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Identification of Non-Point Sources of Nutrient Loading and Proposed Best Management Practices for Browns Gulch, Silver Bow County, MT

Sarah Hamblock
Montana Tech of the University of Montana

IDENTIFICATION OF NON-POINT SOURCES OF NUTRIENT LOADING AND PROPOSED BEST MANAGEMENT PRACTICES FOR BROWNS GULCH, SILVER BOW COUNTY, MT

by

Sarah Hamblock

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Abstract

Nutrients are essential to support stream ecosystems, however, if present in excess may lead to growth of algal blooms, excessive aquatic weeds, and alteration of natural aquatic ecosystems. Silver Bow Creek (SBC), the headwater stream of the Clark Fork River, is listed as impaired for nutrients (total nitrogen (TN) and total phosphorus (TP)), by the Montana Department of Environmental Quality. Browns Gulch is a major tributary to SBC, and drains agricultural and forested lands. To meet target nutrient TMDL concentrations in SBC, the tributary load inputs of TN and TP must be reduced by 93% in Browns Gulch. To identify the sources of nutrients, surface water samples were collected and analyzed for TN and TP at three flow stages from locations distributed along the stream. Browns Gulch water quality data exhibited that, in all the flow stages, TN and TP loads increase from up to down-stream. Data analysis suggests that runoff from agricultural lands (during spring and summer) is the main source of TN, and a supplemental source of TP. Irrigated and grazed areas correspond with a sharp increase in the stream nutrient load. Specific conductivity and alkalinity concentrations were highly correlated with TP concentrations at each flow stage. The Lowland Creek Volcanics are the predominant geologic formation in the Browns Gulch watershed and may be contributing consistent low levels of TP via groundwater. To reduce agricultural non-point source inputs, three best-management practices (BMPs) are recommended: vegetated filter strips, riparian exclusion fencing, and off-stream water sources. It is hypothesized that effective implementation of one of the three proposed BMPs on each agricultural property will significantly reduce tributary TN load input to below to TMDL load allocation. The TP load input will be reduced, however to quantify this reduction, an understanding of the fraction of phosphorus originating from agriculture is required.

Keywords: Non-point source, nutrients, Browns Gulch, TMDL, best management practices

Dedication

I want to dedicate this work to my lovely parents, Mike and Patty Hamblock, and my favorite adventure partners, Joe Paul and Norma Jean Schmechel.

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*Committee Member

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Glossary of Terms and Acronyms

Term	Definition
MTDEQ	Montana Department of Environmental Quality
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
BMP	Best management practice
SBC	Silver Bow Creek
BG	Browns Gulch
NFS	National Forest Service
LCV	Lowland Creek Volcanics
NRCS	Natural Resource Conservation Service
MGMB	Montana Bureau of Mines and Geology
BSB	Butte-Silver Bow
GPS	Geographic positioning system
TKN	Total Kjeldahl nitrogen
BOD	Biological oxygen demand
DO	Dissolved oxygen
QC	Quality control
QA	Quality assurance
DI	Deionized water
TSS	Total suspended solids

SC	Specific conductivity
IC	Ion chromatography instrument
UV-VIS	UV and visible spectrum spectrophotometer
USGS	United States Geological Survey
EPA	Environmental Protection Agency
GIS	Geographic information systems
MRL	Minimum reporting limit
VFS	Vegetated filter strips
GWIC	Ground Water Information Center
STEPL	Spreadsheet Tool for Estimating Pollutant Load

1. Introduction

1.1. Nitrogen and Phosphorus in Surface Water

Nutrients, nitrogen and phosphorus, are essential to support stream ecosystems. Aquatic plants and algae utilize nutrients found in stream sediment and dissolved in the water for growth and survival. However, when nutrient concentrations are elevated above natural levels, the innate nutrient cycling can be disrupted. This problem is commonly referred to as eutrophication. High levels of nutrients promote the proliferation of aquatic weeds and algae. Certain species of algae, such as cyanobacteria, can create toxic drinking water conditions in the surface water. Once the stream conditions are no longer optimal, large amounts of algal death occurs. Microbiological decomposers use the dead plant and algae mass as a food source and consume large amounts of dissolved oxygen for the decomposition process. Eutrophic streams do not support healthy macroinvertebrate or fish populations, due to the lack of dissolved oxygen. Aesthetically, high levels of algae and aquatic weeds are unsightly and can have a distasteful odor.

Human consumption of water contaminated with nitrogen, in the form of nitrate, can be a serious health hazard. The Environmental Protection Agency (EPA) has established a "Maximum Contaminant Level" of 10 mg/L nitrate, and 1 mg/L nitrite (EPA, 2009). In the body, nitrates are converted to nitrites. In the blood-stream, nitrites compete with oxygen to bind hemoglobin in the red blood cells. Decreases in cellular oxygen lead to reduced cellular function, thyroid dysfunction, reduced hormone production, and a blue coloring of the skin (World Health Organization, 2011). This clinical condition is called methemoglobinemia, or more commonly, blue-baby syndrome. Acute ingestion of nitrate-contaminated water generally does not result in permanent detrimental effects to human health. However, adults with compromised immune systems or irregular digestive tracts and infants are at higher risk of complication (Washington State Department of Health, 2012).

The Montana Department of Environmental Quality (MTDEQ) established numeric nutrient criteria standards, and narrative water quality criteria, with the intent of controlling nutrient pollution in Montana surface waters (MTDEQ, 2014, a). The nutrient standards apply to total nitrogen (TN) and total phosphorus (TP) surface water concentrations throughout the growing season from July 1 to September 30. The standards were developed for each of Montana's ecoregions to account for differences in hydrography and natural background levels (Suplee et al., 2013). The calculations of the nutrient criteria considered natural background sources, and aimed to achieve healthy TN:TP ratios and algal growth.

1.2. Water Quality in the Upper Clark Fork Watershed

The Clark Fork River Watershed drains a large portion of Western Montana, as shown in Figure 1. In recent years, many Clark Fork River tributaries, including Silver Bow Creek (SBC), have been listed as impaired for nutrients, TN and TP, on Montana's 303(d) list (MTDEQ, 2014, a). An impairment listing is determined by whether a waterbody supports its "beneficial uses." Beneficial uses include drinking water, fish and waterfowl habitat, recreation, agricultural, and industrial purposes. SBC is listed as "Not Supporting" for aquatic life, drinking water, and primary contact from recreation. It is listed as "Supporting" for agriculture.

To address the nutrient impairment, the MTDEQ released the Upper Clark Fork Phase 2 Sediment and Nutrients Total Maximum Daily Load and Framework Water Quality Improvement Plan in 2014. The plan proposes to mitigate nutrient loading by allocating calculated loads to point sources and sub-watersheds that discharge to SBC. Sub-watershed load allocations account for nutrient additions from “agriculture, silviculture, mining, and subsurface wastewater treatment and disposal sources,” (MTDEQ, 2014, b).

Browns Gulch is one of five major tributaries to SBC, contributing 26% of the SBC stream flow (MTDEQ, 2003). MTDEQ used water quality data, collected from 2007 to 2012 at the confluence of Browns Gulch and SBC, to develop the Browns Gulch load allocation. Results from this data showed that the average TN concentration was 3.09 mg/L and the average TP concentration was 0.32 mg/L. The target TN concentration is ≤ 0.300 mg/L and TP concentration is ≤ 0.030 mg/L, both of which are based on the numeric nutrient criteria for the Middle Rockies Ecoregion III (Suplee et al., 2013). A three-year summer average discharge (6.35 cfs) was used to calculate the current and allocated load. The load allocation accounts for background concentrations of a 0.095 mg/L TN and 0.01 mg/L TP, which are also based on Middle Rockies Ecoregion III TN and TP criterion.

The calculated load allocation for Browns Gulch is 7.03 lbs/day TN and 0.69 lbs/day TP. The measured actual load contributions were 102.7 lbs TN/day and 10.63 lbs TP/day (MTDEQ, 2014, b). Based on the load allocation and current stream conditions, both TN and TP loads must be reduced by 93% in Browns Gulch to achieve target loads.

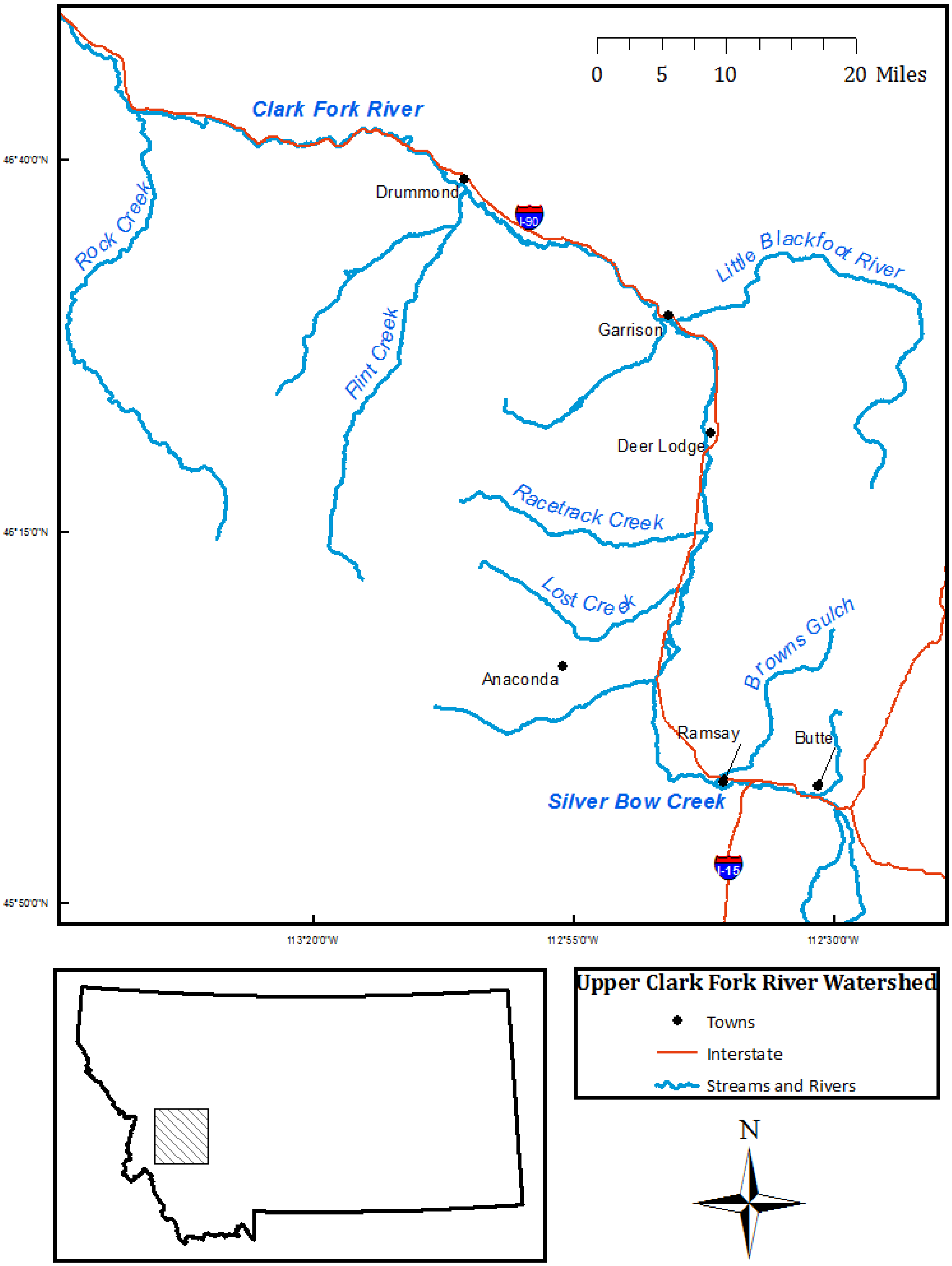


Figure 1. Upper Clark Fork Watershed map.

1.3. Browns Gulch

1.3.1. Geography

The Browns Gulch watershed is approximately 54,380 acres, primarily comprised of forested montane areas and semi-arid foothills. The 18.8 mile stream flows south then southeast to join SBC at Ramsay, MT. Significant tributaries within the Browns Gulch watershed include American Gulch, Alaska Gulch, Flume Gulch, Telegraph Gulch, Meadow Gulch, Hail Columbia Gulch, Orofino Gulch, and Bull Run Gulch. To clarify, in this region, “gulch” is the word used to describe a stream. The watershed is bounded by mountainous Beaverhead-Deer Lodge National Forest Service land on the east and west. The primary north-south mountain ridges are within the Boulder Batholith geological complex, and have no official names. The southern end of the watershed opens up into a broader basin, where SBC is the low point. Figure 2 is a detailed site map of the Browns Gulch Watershed including major tributaries, roads, and public lands.

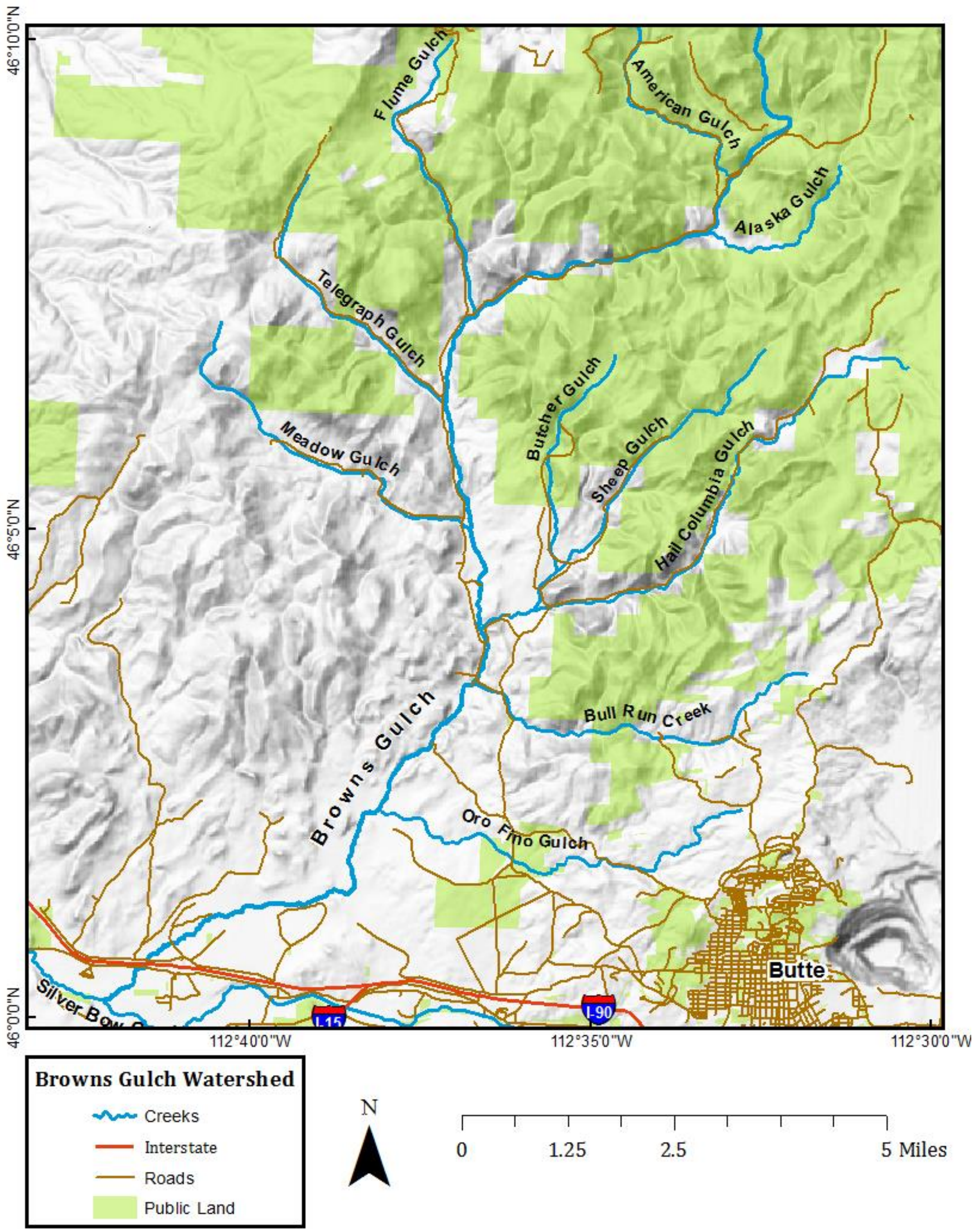


Figure 2. Browns Gulch Watershed.

1.3.1. Land-use

Land-use in the Browns Gulch basin is primarily commercial agriculture and logging or rural residential. The head of the stream is in the Beaverhead-Deerlodge National Forest, Butte Ranger District. This public land is managed for timber harvest, livestock grazing, and dispersed recreation (USDA, 2009). After the National Forest Service (NFS) land, Browns Gulch passes through 14 private landholdings. Landowners mainly use the land for grazing cows and sheep, production of alfalfa and grass, with and without irrigation. The following map, Figure 3, shows the locations of residences within the watershed, as well as major land-use categories compiled by the Montana Department of Revenue in the 2014 Revenue Final Land Unit (FLU) Classification (MTDOR, 2014).

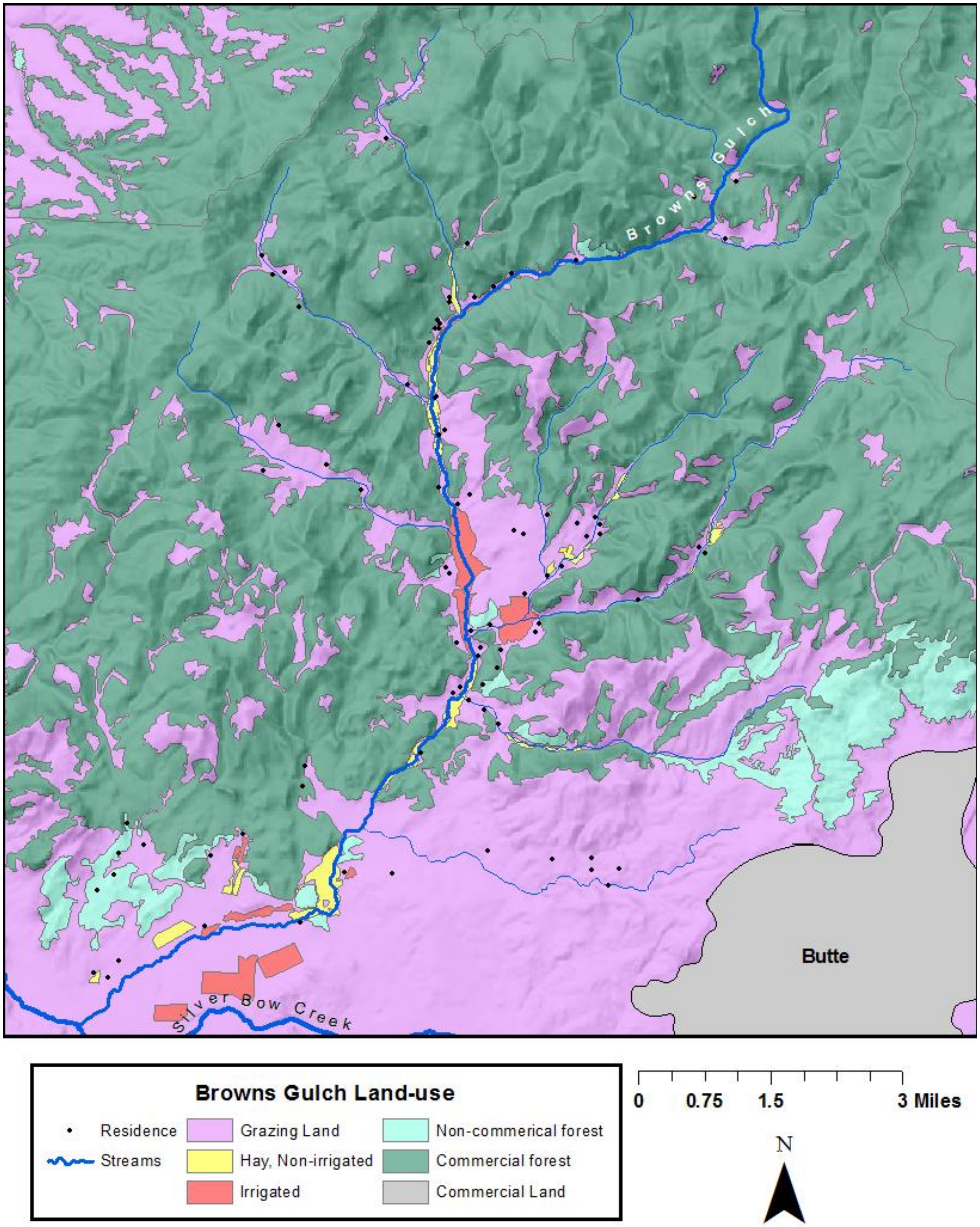


Figure 3. Land-use in Browns Gulch and locations of residences.

1.3.1. Geology

The geology underlying Browns Gulch is regionally unique. The watershed is bounded on either side by the Boulder Batholith. The batholith is a granitic pluton from the late Cretaceous Period. The majority of the watershed lies within the Eocene Epoch Lowland Creek Volcanics (LCV) (Dudás et al., 2010). The alluvium varies over the course of the stream from fractured volcanics to decomposing and fractured granitic pluton to shales and sandstones (GWIC, 2014). Surficial geologic mapping of this area is a focus of continual study due to the potential hazards associated with regional faults and the high value of ores in the surrounding area. The goal of an ongoing regional project is to investigate and map specific geologic facies within the LCV region (Scarberry, 2015). The Browns Gulch and tributary alluvium was characterized by Derkey and Bartholomew in 1988 (Derkey and Bartholomew, 1988). Houston and Dilles mapped the eastern edge of the Browns Gulch watershed in 2013, with emphasis on contacts, faults, and veins (Houstan and Dilles, 2013).

The LCV geologic region lies within the Great Falls Tectonic Zone, which is a northeast trending geologic feature that spans an area from Central Idaho to Southern Saskatchewan (Lewis, 2014). This zone is characterized by eroded andesitic volcanoes. In the LCV unit, two major eruptive cycles occurred in which ash was dispersed, followed by a collapse of the lava dome. These eruptions and caldera collapse are characterized by irregularly aligned breccia and welded tuff deposits in the LCV (Scarberry, 2015). This series of events caused the buildup of approximately 1800 m of volcanic material cover (Elliot and McDonald, 2009). Although this volcanic material was subsurface for millions of years, weathering has caused approximately 7.5 km of vertical erosion in this area. This volcanic activity contributed to the concentration of precious metals in veins under the Butte hill and surrounding area.

Figure 4 is a surficial geologic map produced using data available from Montana Bureau of Mines and Geology (MBMG), and created by Reed Lewis in 1998 (Lewis, 1998).

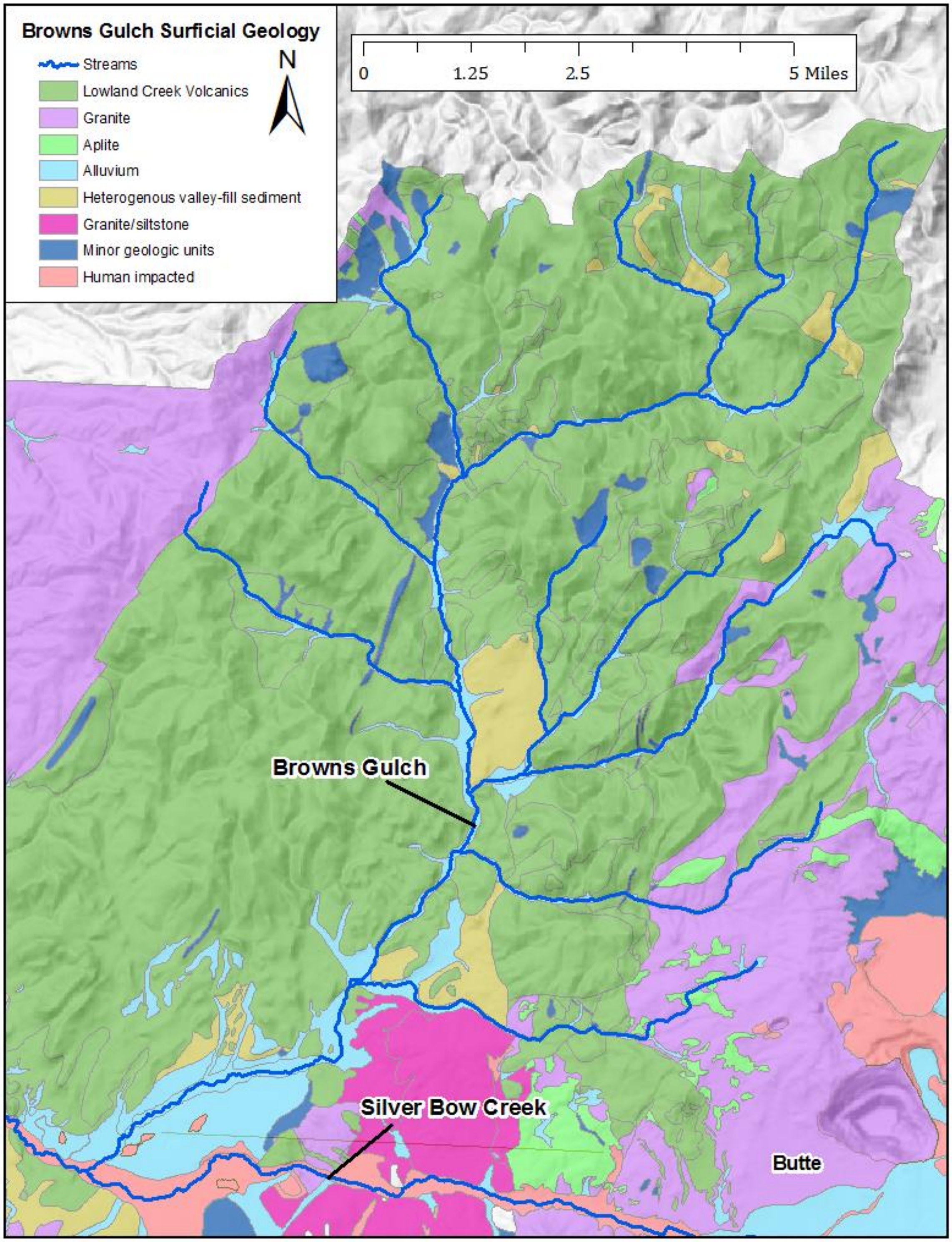


Figure 4. Surficial geology in Browns Gulch.

1.3.1. Hydrology

The watershed receives approximately 10 inches of precipitation annually (NCDC, 2015). The steep, forested slopes along Browns Gulch and tributary streams hold snow throughout most of the winter months. Peak stream flow occurs from mid to late May, due to seasonal rain and snow-melt runoff (Pick and Kellogg, 2006). MTDEQ measured summer stream flows in the lowest reaches from 2007 to 2012 for the development of the nutrient TMDL. The reported six-year summer average was 6.35 cfs (MTDEQ, 2014, b). The stream is hypothesized to be an intermittent gaining stream, gaining groundwater flow over the course of the stream (Bollman, 2005).

In a 2006 riparian assessment report, Natural Resource Conservation Service (NRCS) watershed scientists documented 29 irrigation structures along Browns Gulch (Pick and Kellogg, 2006). During the growing season, flood irrigation is used in the upper and mid-reaches of the stream for grass production. In the lowest reaches, center-pivot sprinklers are used to irrigate alfalfa fields. The majority of water rights are held by landowners in the lower stretches, where a large diversion dam was constructed in recent years (Pick and Kellogg, 2006).

The upper third of the stream is primarily a Rosgen stream type B, which is characterized by a 2-4% channel slope and minimal sinuosity. The mid-third of the stream transitions to a G stream type, which is characterized by a 2-4% channel slope and moderate sinuosity. The lowest third is predominantly an E stream type, which is characterized by a less than 2% grade and high sinuosity (Staats and McDowell, 2014). Sediment deposition, especially in the low velocity reaches, has been determined to impair beneficial uses of the stream (MTDEQ, 2014, b). Reduced stream velocity allows suspended material to settle, reducing stream bed substrate diversity. Unpaved roads and stream bank instability in the upper reaches due to grazing and minimal woody and herbaceous plant cover promotes greater suspended solids loads in the stream (MTDEQ, 2014, c).

1.4. Potential Nutrient Sources

Water pollutant discharges to surface water are classified as point or non-point sources (NPS). NPSs distribute pollutants over a wide area and are therefore challenging to pinpoint. In agricultural and rural settings, NPSs are the primary pollutant inputs. A highly regarded study by the EPA determined that stream nutrient levels are highly correlated to land-use (Omernik, 1976). The main land-use categories that contribute N and P loads, from greatest to least are; agriculture, urban land, and forests. In non-urban landscapes, runoff from agriculture, pastures, animal feed lots, and logging operations, and leachate from old or faulty septic system are the most common anthropogenic nutrient sources (Carpenter et al., 1998). However, natural sources of nitrogen and phosphorus can contribute significant loads to the stream. A study conducted in the Sierra Nevada Mountains found that nitrogen-containing bedrock contributed considerable concentrations of nitrate to regional streams (Holloway et al., 1998). An addendum to the "Scientific and Technical Basis of the Nutrients Criteria for Montana's Wadeable Streams and Rivers, Update 1," reported elevated phosphorus concentrations in surface water in areas with high percentages of volcanic geology (MTDEQ, 2013).

1.4.1. Anthropogenic Sources

1.4.1.1. Septic Systems/Human Sewage

The Browns Gulch watershed has a relatively low septic system density (approximately one system per square mile). Septic leachate is characterized by high nitrate levels. The initial waste composition within septic tanks primarily contains organic nitrogen (Toor et al., 2014). The anaerobic conditions in the septic tank cause most of the organic nitrogen to convert to ammonium by ammonification. The septic effluent that leaches from the septic system into the unsaturated zone of the drainfield contains a high fraction of ammonium as well as organic nitrogen and nitrate (Toor et al., 2014). The ammonium can be nitrified to nitrate, adsorbed on soil particles, or volatilized as ammonia gas. The organic nitrogen either adsorbs on soil particles or is converted to ammonium. Nitrate is highly mobile porous aquifers, and therefore often leaches to groundwater. Denitrification is the main process by which nitrate is removed from the drainfield (Toor et al., 2014). Proper placement and installation of septic systems can provide more opportunities for nitrification to occur before the leachate reaches groundwater. The majority of septic systems in the Browns Gulch basin were installed before 1979 (BSB Health Department, 2014). Therefore, it is possible that drainfield sites were improperly located, designed, and/or installed.

1.4.1.1. Agriculture

Fertilizer application and manure are the primary agricultural sources of N and P (Carpenter et al, 1998). It is not confirmed that fertilizer is used in the Browns Gulch area, however it is unlikely. In the upper stretches, cows and sheep are grazed on riparian pastures from late fall through spring. Often, the cattle are fed hay and therefore maintained in greater numbers per acre than is recommended for grazing (Personal Observation, 2014, NRCS, 2009). In the lower stretches, cattle pastures are rotated at approximately 2-3 month intervals.

In manure, a portion of the nitrogen content is readily available to plants and soil in the form of nitrate, NO_3^- . Nitrate is highly soluble ion that remains in solution until it is processed by plants or microorganisms. Organic nitrogen is fairly insoluble and unavailable to plants, but can be mineralized by soil microbes to produce soil ammonium (Murphy et al., 2000). Soil ammonium can be nitrified to nitrate by soil microbes, which is highly mobile (Johnson et al., 2005).

The majority of phosphorus in manure is in the form of orthophosphate, PO_4^{3-} (Zhang et al., 2003). This inorganic molecule is highly sorptive and therefore binds to particulate matter. Under certain conditions, it can form metal-phosphate precipitates with calcium, iron, and aluminum. Organic phosphorus makes up the lesser fraction of phosphorus content in manure, and like organic nitrogen, is mineralized by soil microorganisms (Zhang et al., 2003). If the top layer of soil is saturated with phosphorus, either with metal phosphates or soil-bound phosphorus, runoff and flooding can easily transport phosphorus from the manure source into surface water.

1.4.2. Natural Sources

1.4.2.1. Geology

Volcanic soils and rock formations are associated with phosphorus retention and leaching (McClellan et al., 2007). As previously stated, the Browns Gulch watershed is dominated by the LCVs. These volcanics have been mapped to identify individual geologic units. Geochemical analysis of the “Tat” unit, which is primarily rhyolitic air-fall and welded ash-flow tuffs, showed an average 1140 mg/L phosphorus concentration (Scarberry, 2015). In Hawaiian soils derived from similar volcanics, phosphorus concentrations average 700 mg/L (McClellan et al., 2007). Previous studies have shown that phosphorus content in rock is the strongest predictor of phosphorus stream concentrations (Olson and Hawkins, 2013). Chemical weathering is the only process by which rock-bound phosphorus becomes soluble (Smeck 1973, Froelic, 1988). Weathering has a greater effect on sandy volcanic soils, which are susceptible to phosphorus leaching. Recent analysis of the Browns Gulch LCV indicates that the exposed and subsurface rocks are old, weathered, and unconsolidated volcanics. Specifically, the Tat unit is not well indurated and is physically fractured due to tectonic plate movement. Primary faults within the Tat unit may provide a route by which groundwater leaches phosphorus into the alluvium. Additionally, phosphorus-laden sediment may contribute to total phosphorus levels.

Prior to the development of TMDLs, the MTDEQ conducted a study into the derivation of site-specific nutrient criteria for streams in volcanically influenced areas (Suplee and Schmidt, 2013). The goal study of the study was to use a predictive multi-variable model to determine reasonable background concentrations for volcanically influenced streams in the Upper Clark Fork River basin. The study determined that volcanic geology is statistically predictive of elevated phosphorus levels in streams. Taking into account the high percentage of volcanic geology in Browns Gulch, the site specific phosphorus numeric criteria was determined to be 0.04 mg/L. This concentration is 0.01 mg/L greater than the numeric nutrient criteria used in the development of the TMDL load allocations.

1.5. Best Management Practices

Best Management Practices (BMPs) are a common and effective pollution control technique. BMPs range from land-use management to installed structures. The goal of BMPs is to reduce pollution at the source or to reduce the amount of pollution that reaches surface water or groundwater. In rural and agricultural settings, sediment and nutrient loads are most often the target of BMPs. The main agricultural land-use practices in Browns Gulch are grazing of livestock, flood irrigation, and hay production.

To reduce sediment, phosphorus, and nitrogen deposition in surface water from overland flow, filter strips (vegetated filter strip) can be effectively used (Schilling et al., 2014, Tetra-Tech, 2003). A filter strip is a strategically located, 50-100 meter strip of land along a surface water body, which is vegetated and separated from crop land. The vegetation impedes water flow, acting as a filter for suspended material. The vegetation can also remove organic matter before it reaches the stream (Tetra-Tech, 2003). Another benefit of buffers is the reduction of stream bank erosion.

Intensive rotational grazing is another effective agricultural BMP (Agouridis et al., 2005). Restricting grazing in riparian areas to only short periods of time, when the soil moisture is low, creates the least streambank and water quality degradation (Marlow et al., 1987). Protection of riparian areas when vegetation is emerging, regenerating, and settling seed should be incorporated into the grazing plan (Agouridis et al., 2005). Proper planning and implementation of this BMP can maintain or improve water quality and quantity (Tetra-Tech, 2003).

Stream bank fencing is used to prevent livestock from grazing in the riparian area. One study reported that exclusionary fencing promoted three times the vegetation growth in a two year period (Scrimgeour and Kendall, 2003). Benefits of increased vegetative cover and fewer surface disturbances include increased bank stability, filtration of runoff, and greater water temperature stability. Trees, shrubs, and long and short rooted grasses improve stream bank stability and reduce suspended sediment, nitrogen, and phosphorus loads to surface water (Agouridis et al., 2005).

1.6. Objectives

This study was developed to investigate the nutrient load contribution from Browns Gulch to SBC. The first objective was to quantify nutrient loads, TN and TP, in Browns Gulch at three flow stages. The second objective was to determine sources of nutrient loads. The final objective was to recommend Best Management Practices to reduce nutrient loads in the stream.

2. Methods

2.1. Nitrogen and Phosphorus Sampling Strategy

The nitrogen and phosphorus sampling strategy outlined in the following section was used in this study and will serve as a framework for future studies on Browns Gulch. Analysis techniques were chosen based on available laboratory resources, similar studies found in literature, and commonly used methods.

2.1.1. Field sampling: locations and methods

Surface water samples were collected three times over a five month period, from May to October, 2014 from Browns Gulch. Data from the May 30-31 sampling event represented high-flow runoff conditions. Data from the July 22-23 sampling event represented growing-season conditions. Data from the October 27-28 sampling event represented base-flow conditions. A detailed explanation of sampling locations and sampling methods is outlined in the following sections.

2.1.1.1. Sampling locations

Field visits prior to sampling season, conversations with landowners, and reference to previous sampling events on Browns Gulch guided the establishment of sampling locations. Nine private landowners granted permission to access and sample the creek on their property. Near tributaries, sampling points were located downstream of the tributary mixing zone, to capture the entire contribution from the tributary. The sampling locations were evenly distributed along the stream. Sufficient mapping, aerial photographs, and GPS coordinates of the sampling locations will be useful for consistency with future studies. Exact locations of the field sampling are shown in Figure 5. GPS coordinates and site photos for each sampling location were recorded and are available in Appendix A. River miles were calculated using the "Measure" tool in ArcGIS and a 2013 aerial photo. This method accounted for stream sinuosity.

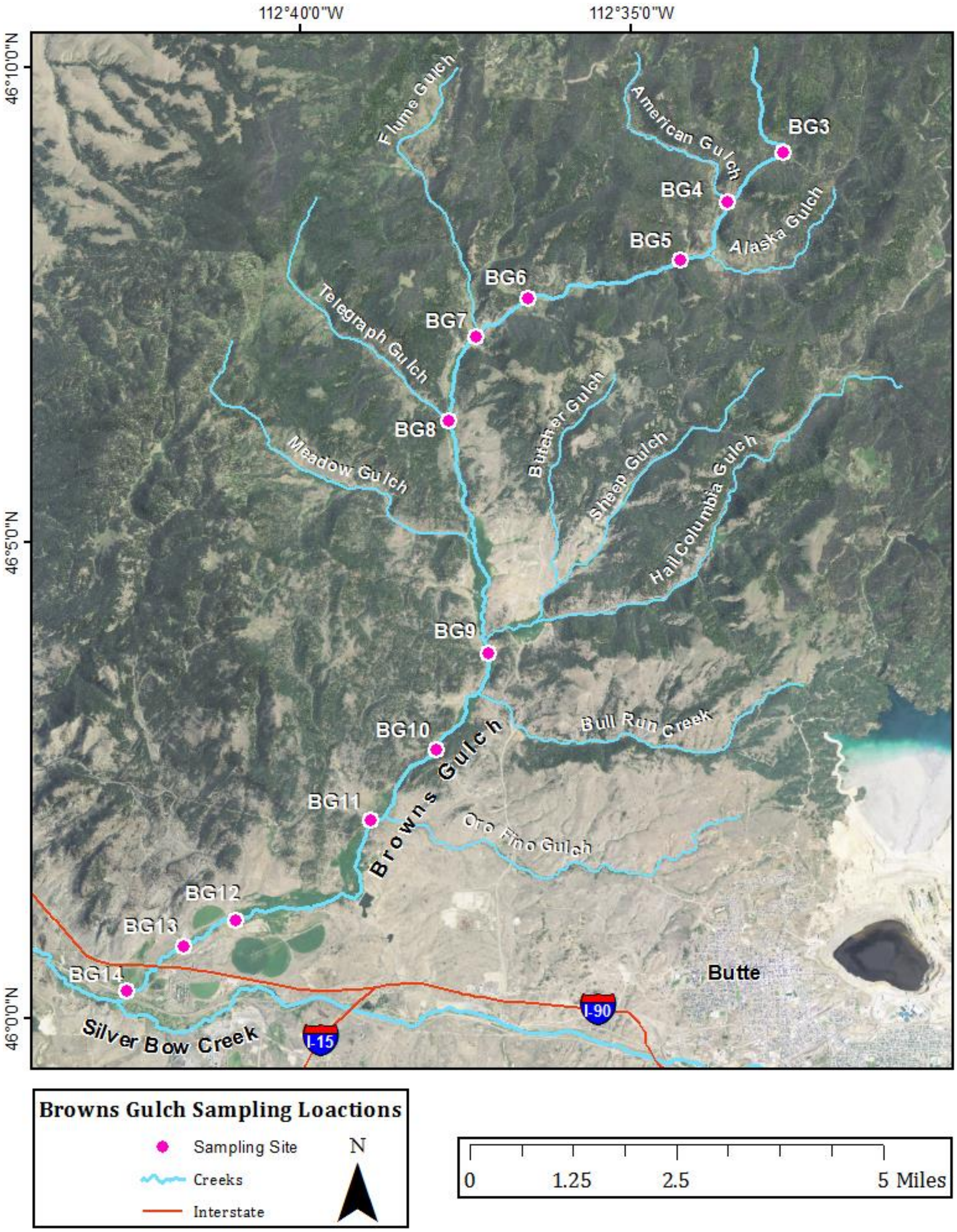


Figure 5. Surface water sampling locations on Browns Gulch.

2.1.1.2. Flow measurement procedure

Stream flow rate was measured using a Marsh McBirney Flo-mate and following the USGS midsection method. A tape measure was used to measure the width of the stream, perpendicular to stream flow. A wading rod was utilized to adjust the Flo-mate for stream velocity measurements at 0.6 the depth below the water surface. Twenty flow measurements were recorded across the width of the stream at equal intervals (John, 2003).

2.1.1.3. Sampling procedures and preservation

Table I summarizes the sampling techniques, sampling frequency, necessary sample containers, preservation techniques, and holding times for the analytical parameters and field measurements. Water samples were collected at designated sampling locations from flowing water. The grab samples were collected in wide mouth plastic high-density polyethylene (HDPE) bottles. The bottles were new and rinsed three times with the water being sampled. The sample bottle was used to collect flowing water in the middle of the stream. Samples were collected at a single depth, the sample bottle was un-capped, plunged into the water with the mouth facing down, and filled at approximately half of the depth.

Table I. Sample collection and preservation field techniques.

Analytical Parameter/ Field Measurement	Number of Sample Stations	Number of Samples	Sample Type	Sample Treatment	Preservation and Storage
Alkalinity	12 during R*, 8 during G*,B*	1 per R,G,B plus duplicates	Grab	-	-
Turbidity			Grab	Analyze immediately	-
pH, Specific conductivity, DO, Temperature			Mid-stream Measurement	Analyze immediately	-
Total suspended solids			Grab	-	Chill to 4°C, 7 days
Major anions			Grab	0.45 µm filter	Chill to 4°C, 48 hours
TP, NH_3-N, TKN-N			Grab	-	Acidify to pH < 2, Chill to 4°C, 28 days
BOD, chlorophyll	4 (R,G,B)		Grab	-	Chill to 4°C, 24 hours in dark

R*=runoff (May), G*=growing season (July), B*=baseflow (October)

The sample collection and preservation requirements for the sampling parameters and field measurements are detailed in subsections 2.1.1.2.1. to 2.1.1.2.5..

2.1.1.3.1. Inorganic anions

Samples for inorganic anions, Cl^-, F^-, Br^-, NO_2^-, NO_3^-, SO_4^{-2}, PO_4^{-3}, were collected in 500 mL plastic wide mouth HDPE bottles. Samples were filtered through a 0.45 μm filter in the field into a new 250 mL plastic HDPE bottle. Samples were capped and chilled to 4°C.

2.1.1.3.2. BOD

Samples for BOD analyses were collected in 1 L plastic of glass bottles. Samples were capped and chilled to 4°C.

2.1.1.3.3. Solids and alkalinity

Samples for total suspended solids and alkalinity were collected in 250 mL wide mouth plastic HDPE bottles. Samples were capped and chilled to 4°C.

2.1.1.3.4. Total Kjeldahl Nitrogen, ammonia, and total phosphorus

Samples for Total Kjeldahl Nitrogen, ammonia, and total phosphorus were collected in new, acid-washed 500 mL wide mouth plastic HDPE bottles. Samples were preserved with sulfuric acid to a pH of 2. Samples were capped and chilled to 4°C.

2.1.1.3.5. Chlorophyll

Chlorophyll samples were collected in 1 L plastic or dark glass bottles. Opaque bottles were wrapped in aluminum foil to protect sample from sun exposure. Samples were capped and chilled to 4°C.

2.1.1.4. Field Quality Control

Field quality control (QC) samples were used to evaluate the sample conditions from field influences and to assess field contamination and sampling variability. The introduction of substances in the field due to environmental conditions or sampling equipment was assessed through the use of various blanks. The assessment of variability due to sampling techniques, instrument performance and heterogeneity of the matrix being sampled was accomplished through the use of replicates. The following subsections cover field QC.

2.1.1.4.1. Assessment of Field Contamination; Field Blank

Field blanks were collected when dedicated sampling equipment was used; decontamination was not needed. Field blanks were made by adding DI water to a sampling container in the field. A minimum of one field blank was prepared each day during the field sampling. Field blanks were preserved and packaged the same way as the standard samples. Field blanks were collected to evaluate whether contaminants had been introduced into the samples during the sampling event due to ambient conditions or from sample containers. The field blanks were analyzed for inorganic anions, total nitrogen, total phosphorus, and suspended solids.

2.1.1.4.2. Assessment of Field Variability; Field Duplicates

Field duplicate samples were collected simultaneously with the standard sample from the same source under identical conditions, except for being placed in separate sample containers. The field duplicate allows for assessment of laboratory performance by comparison. Ten percent of all samples collected per event were field duplicates.

2.2. Field and Laboratory Analysis

Inorganic ions, TKN, NH_3, TP, alkalinity, and total suspended solids analyses were conducted in the Environmental Engineering Laboratory at Montana Tech by the graduate student conducting the study. The BOD samples were analyzed at the Butte Silver Bow

Wastewater Treatment Plant using the 5-day BOD method. The chlorophyll samples were analyzed at the MSE laboratory, using the acetone extraction method.

Field measurements included temperature, pH, specific conductivity, dissolved oxygen (DO), and turbidity. These measurements were conducted at the time of sample collection. Calibration, analytical methods, and, if applicable, QA/QC, for each of the analytical instruments are detailed in Appendix B. Table II lists the analytical methods used for analysis of all parameters measured.

Table II. Field and lab measurements, instrumentation, and methods.

Analytical Parameter and Field measurements	Analytical Instrumentation	Analytical Method	Equivalent EPA Method
Temperature, pH, specific conductivity, DO	MS5 Hydrolab multiprobe		
Turbidity	DR 890 colorimeter	Method 8237	
Total suspended solids (TSS)	Vacuum filtration unit	EPA Method 160.2	
Cl^-, F^-, Br^-, NO_2^-, NO_3^-, SO_4^{-2}, PO_4^{-3}	Dionex ICS-2100 Ion Chromatography system (IC)	EPA Method 300.0	
Total phosphorus	Hach DR 6000 UV-VIS Spectrophotometer	Method 10210: Ascorbic Acid Method	EPA 365.1 EPA 365.3
Ammonia-nitrogen	Hach DR 6000 UV-VIS Spectrophotometer	Method 10205: Salicylate method	EPA 350.1 EPA 351.1 EPA 351.2
Total Kjeldahl nitrogen	Hach DR 6000 UV-VIS Spectrophotometer	Method 10242: s-TKN Method	Accepted for compliance reporting in many states
Flow rate	Marsh McBirney Flo-Mate 2000	USGS Midsection Method	
Alkalinity	Hach Automated Titration Kit		
BOD_5	Dissolved oxygen sensor	EPA Method 5210 B (5-day BOD Test)	
Chlorophyll	Spectrophotometer	Standard Method: 10200 H	

2.3. Data Processing

Results from the field and laboratory measurements and analysis were compiled in Excel. ArcMap, a GIS mapping software, was used to visually display and qualitatively analyze data.

2.3.1. Flow calculations

Equations 1 through 4 were used to determine stream flows, and were based on the USGS midsection method.

$$Total\ flow\ (cfs) = \sum_{i=1}^{n} flow_i\ (cfs) \quad (1)$$

$$Flow_i\ (cfs) = Area_i\ (ft^2)*velocity_i\ (fps) \quad (2)$$

$$Area\ (ft^2)=width\ (ft)*depth\ (ft) \quad (3)$$

$$Width\ (ft)= ABS(d_n\ (ft)-d_{n+2}\ (ft))/2 \quad (4)$$

where d_n and d_{n+2} are measured distances from the bank

2.3.2. Load calculations

TN and TP loads were calculated using Equation 4.

$$Load\ (lbs/day) = concentration*flow*5.39 \quad (5)$$

where load is measured in lbs/day, concentration is measured in mg/L, and flow is measured in cfs.

$$5.39=(1L/0.0353\ ft^3)*(1g/1000mg)*(1\ lbs/454\ g)*(3600s/h)*(24\ h/day) \quad (6)$$

2.3.3. GIS

Load gradient maps were created by inputting TN and TP load datasets and representing that data as the stream line. The stream line was created by point addition on a 2013 Montana Spatial Data Infrastructure aerial photograph. The map representation of TP and TN loads along the stream assumes that the load is constant between sampling locations.

3. Results

3.1. Flows

Stream flow rates were determined using the USGS midsection method were required to calculate loads. The flow rate in Browns Gulch in May represents spring runoff conditions from snowmelt. Stream flows were relatively similar during the July and October sampling events. A significant decrease in flow after river mile 13.8 (BG 11) occurs due to a water withdrawal at an agricultural diversion dam. During the spring, tributary flows contributed to the total Browns Gulch flow. However, in July and October, these contributions were diminished. The consistent increase in flow rate over the course of the stream in July and October suggests that Browns Gulch is a gaining stream. Between the diversion dam and the confluence with SBC (river miles 13.8-18.8), a general decrease in flow was observed in each sampling event. In this stretch, the stream leaves the narrow canyon and enters the broad alluvial basin adjacent to SBC. In these reaches, the stream is wider and more sinuous, has reduced vegetative cover, and an apparent reduction in velocity. Decreased flows are possibly due to surface water discharge to the alluvial aquifer and/or evapotranspiration. Figure 6 shows stream flow at the three sampling stages.

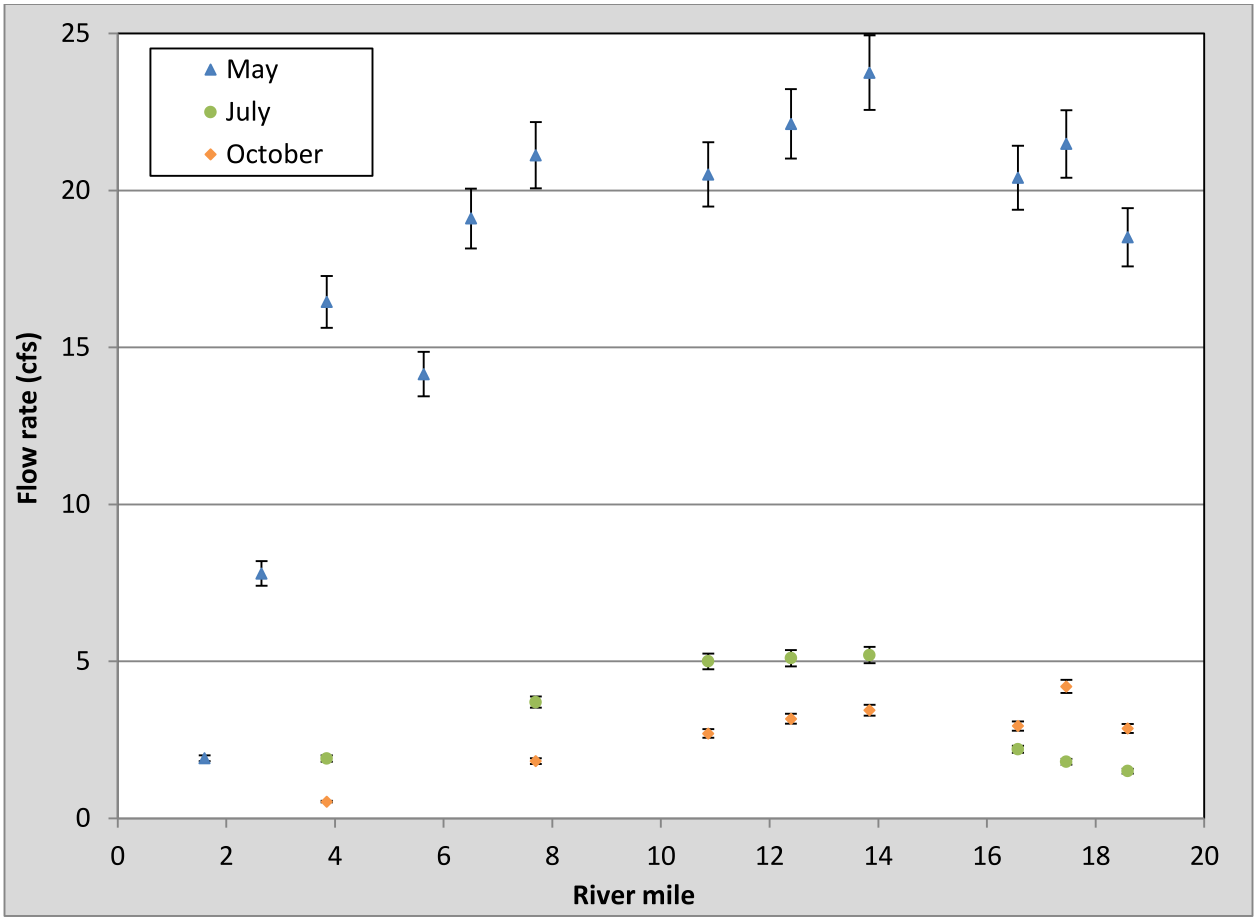


Figure 6. 2014 seasonal flows in Browns Gulch.

3.2. Total Nitrogen Loading

Total nitrogen loads were calculated for each sample site, during May, July, and October. The TN concentration data from the Hach DR-6000 was used to calculate loads. The minimal detection limit for the instrument is 0.46 mg/L TN. However, the minimum reporting level (MRL) for TN is 1.0 mg/L. The TN concentration is calculated by the addition of the measured TKN and NO_3^-/NO_2^- concentrations. The reporting limit for NO_3^-/NO_2^- is 0.23 mg/L and for TKN is 0.77 mg/L. All May and July samples registered concentrations greater than 0.23 mg/L NO_3^-/NO_2^-.

Results from quality assurance instrument testing conducted during this project showed that a 0.5 mg/L TKN standard, measured six times, returned a mean of 0.73 mg/L with a standard deviation of 0.1 mg/L. Often, measurements below the reporting limit are excluded from the reported data, or qualified as “less than MRL”. The quality assurance test showed that measurements in the range of 0.5-0.77 mg/L TKN are less accurate; however, for the purposes of this project, to measure and show general concentration trends, this data set is suitable. Recommendations for laboratory procedure improvements are included in the “Future Work” chapter.

In May, the Browns Gulch load contribution to SBC was 147.7 lbs/day TN. This load exceeds the TMDL load allocation by about 140 lbs/day. In July, the observed load at river mile 18.6 was 8.2 lbs/day. This load exceeds the TMDL load allocation by only 1.2 lbs/day. In October, the final load contribution to SBC was 10.3 lbs/day, exceeding the TMDL allocation by 3.3 lbs/day All measured loads are included in Figure 7.

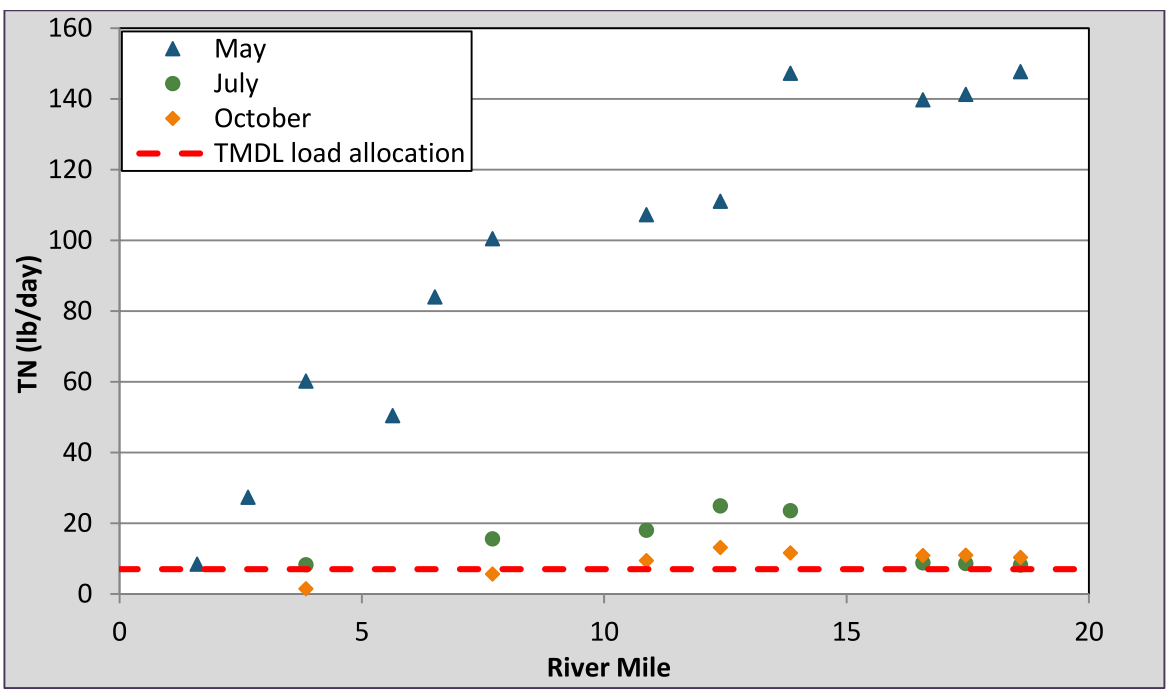


Figure 7. Total nitrogen and the TMDL load allocation.

In Figure 8, May (left line) and July (right line) load gradients were displayed along the course of the stream as a comparison tool. The loads measured in October did not differ greatly from the July data and were therefore not included on the map. Load maps for each sampling event are included in Appendix G.

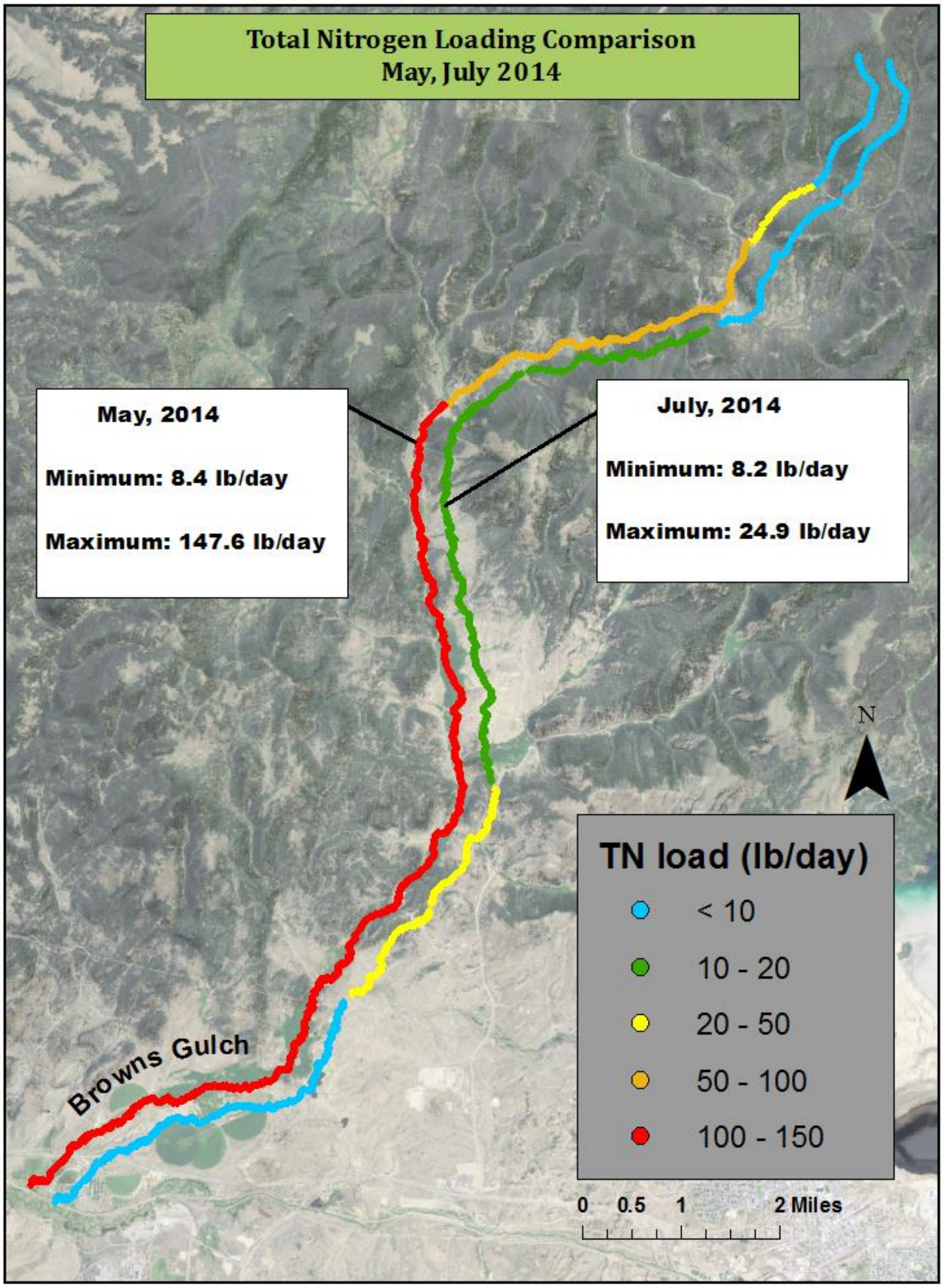


Figure 8. Comparison of total nitrogen loading in May and July, 2014.

The concentration and flow data were compared to determine if either had greater influence on the loading. All measured concentrations were greater than the water quality target concentration of 0.3 mg/L. The TN concentration in May increases over the course of the stream, with an r^2 value of 0.87. The trends for both July and October datasets appear to increase but do not have a strong linear relationship. All measured flows increased until BG 11 (river mile 13.8), where a fraction of the flow was diverted via an irrigation dam. Therefore, the decrease in TN load in July and October is likely a factor of the reduced flow rate, rather than a decrease in concentration. Both TN concentration and flow are presented graphically in Figures 9 and 10.

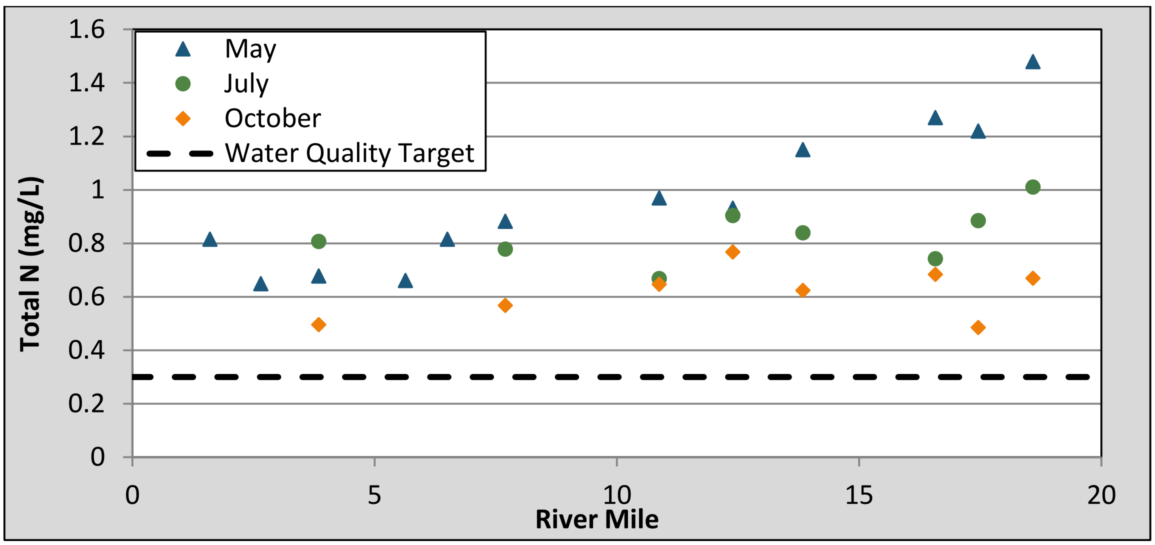


Figure 9. Total nitrogen concentration from upstream to downstream.

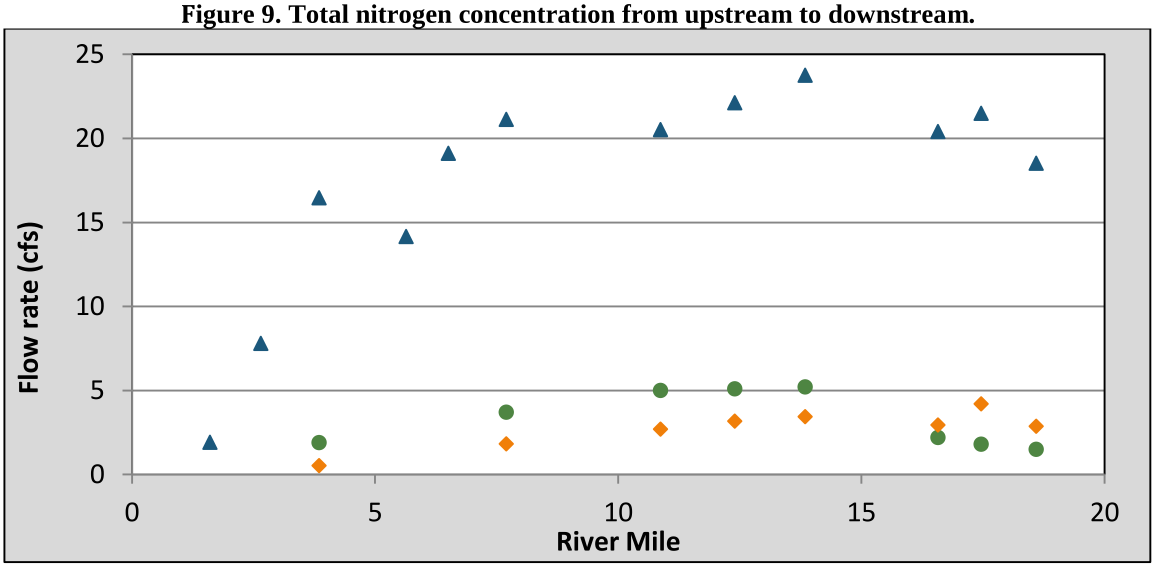


Figure 10. Flow rate from upstream to downstream.

3.3. Total Phosphorus Loading

Total phosphorus loads were calculated for each sample site, during May, July, and October. This data is displayed in Figure 11. The TP concentration data from the Hach DR-6000 was used to calculate loads. The detection limit on the Hach for the Ascorbic Acid Method 10209/10210 was 0.15 mg/L. All measurements were above this concentration. The TP loading patterns were very similar to the TN loading. The final TP contribution from BG to SBC in May was 76.6 lbs/day TP, which is about 76 lbs/day greater than the TMD load allocation. In July and October, BG contributed 6.4 and 6.7 lbs/day TP, respectively. The summer and fall loads are more than 900% greater than the TMDL load allocation.

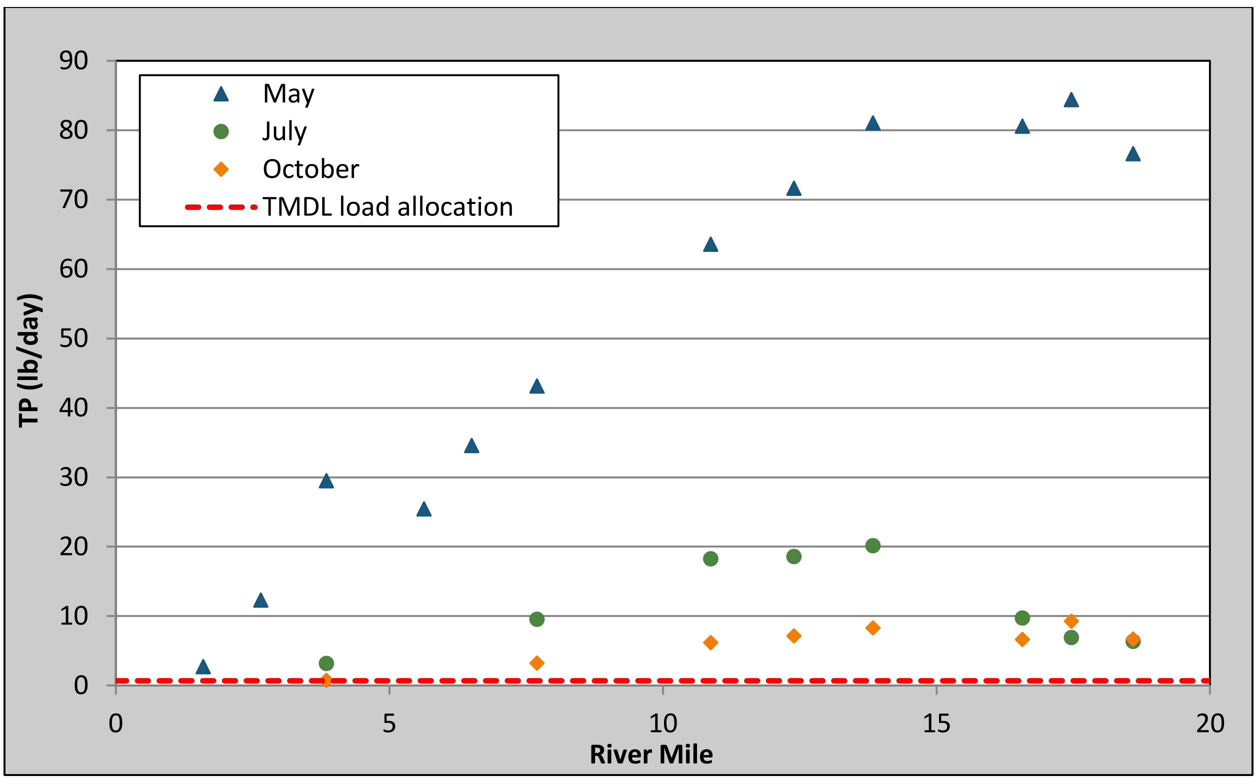


Figure 11. Total phosphorus loads and the TMDL load allocation.

TP load gradients for the May and July data sets were displayed on a Browns Gulch map in Figure 12. The loads were displayed in 15 lbs/day intervals, so the October sampling data was not descriptive in map form. Therefore, it is not presented on the comparison map. Load maps for each sampling event are included in Appendix G.

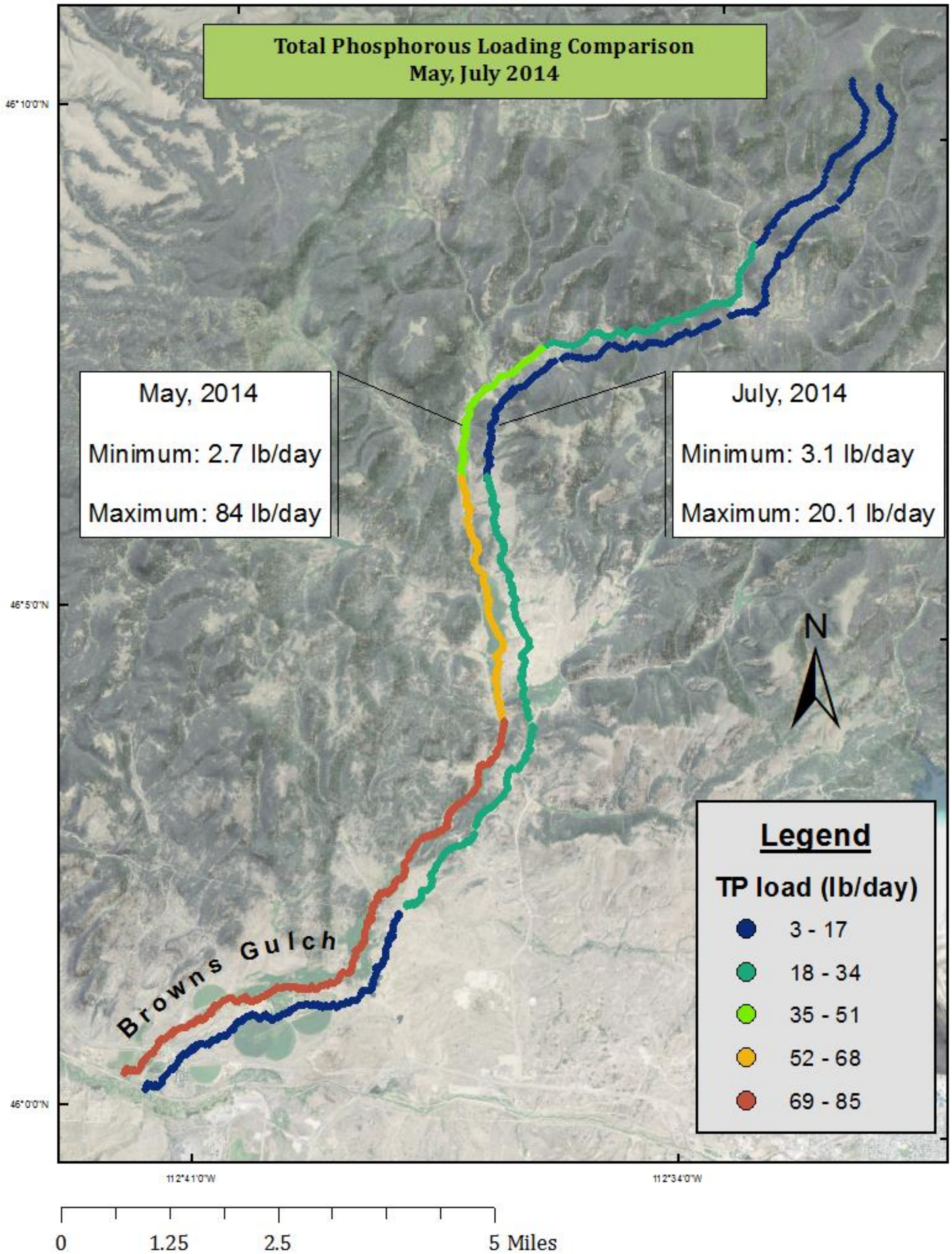


Figure 12. Comparison of total phosphorus loading, May and July 2014.

The TP concentration and flow data was analyzed, to determine the effect of each factor on the loads. This data is shown in Figures 13 and 14. All measured TP concentrations were far greater than the water quality target concentration of 0.03 mg/L TP. Unlike the TN data, a strong positive trend in concentration was observed in May and June, with correlation of determination values of 0.97 and 0.87, respectively. The maximum concentration in October was about 0.43 mg/L, and was consistent over the last 10 stream miles. The flow decrease at BG 11 (river mile 13.8) appears to reduce the loads in every season, though the concentrations increase or stay the same. The lower July flows prevent high in-stream loads despite significant TP stream concentrations.

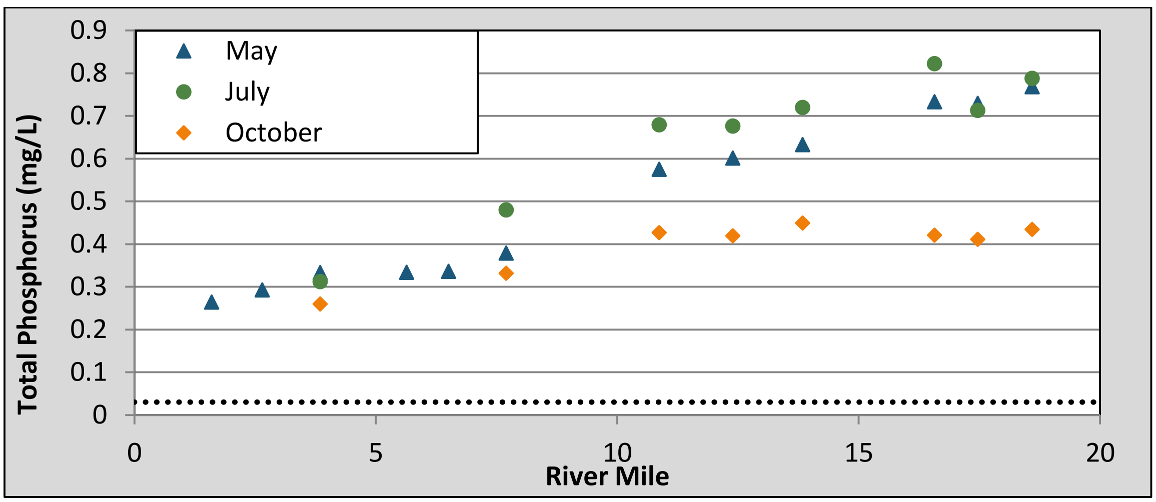


Figure 13. Total phosphorus concentrations from upstream to downstream.

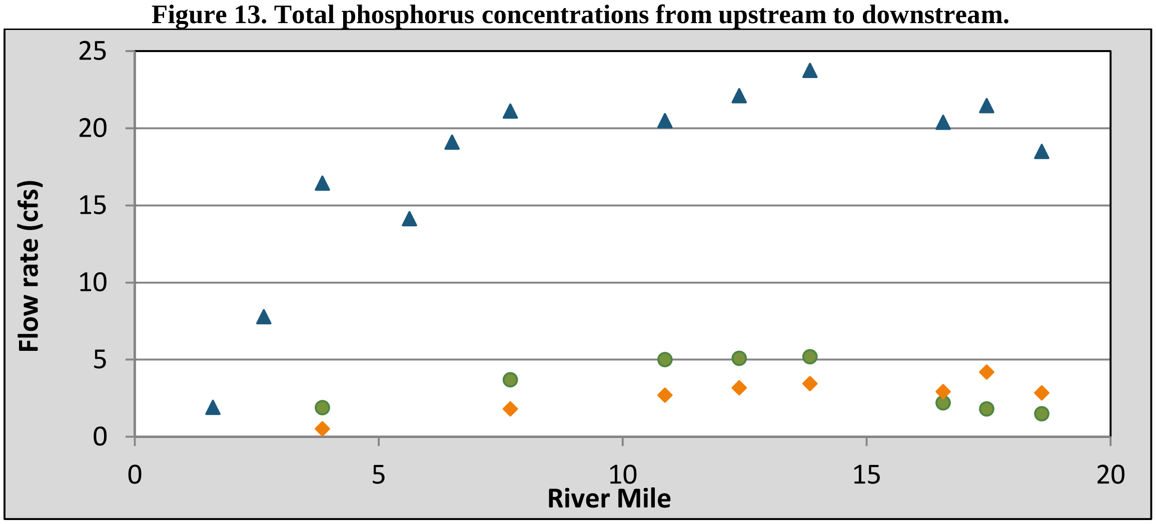


Figure 14. Flow rates from upstream to downstream.

3.4. N:P Ratios

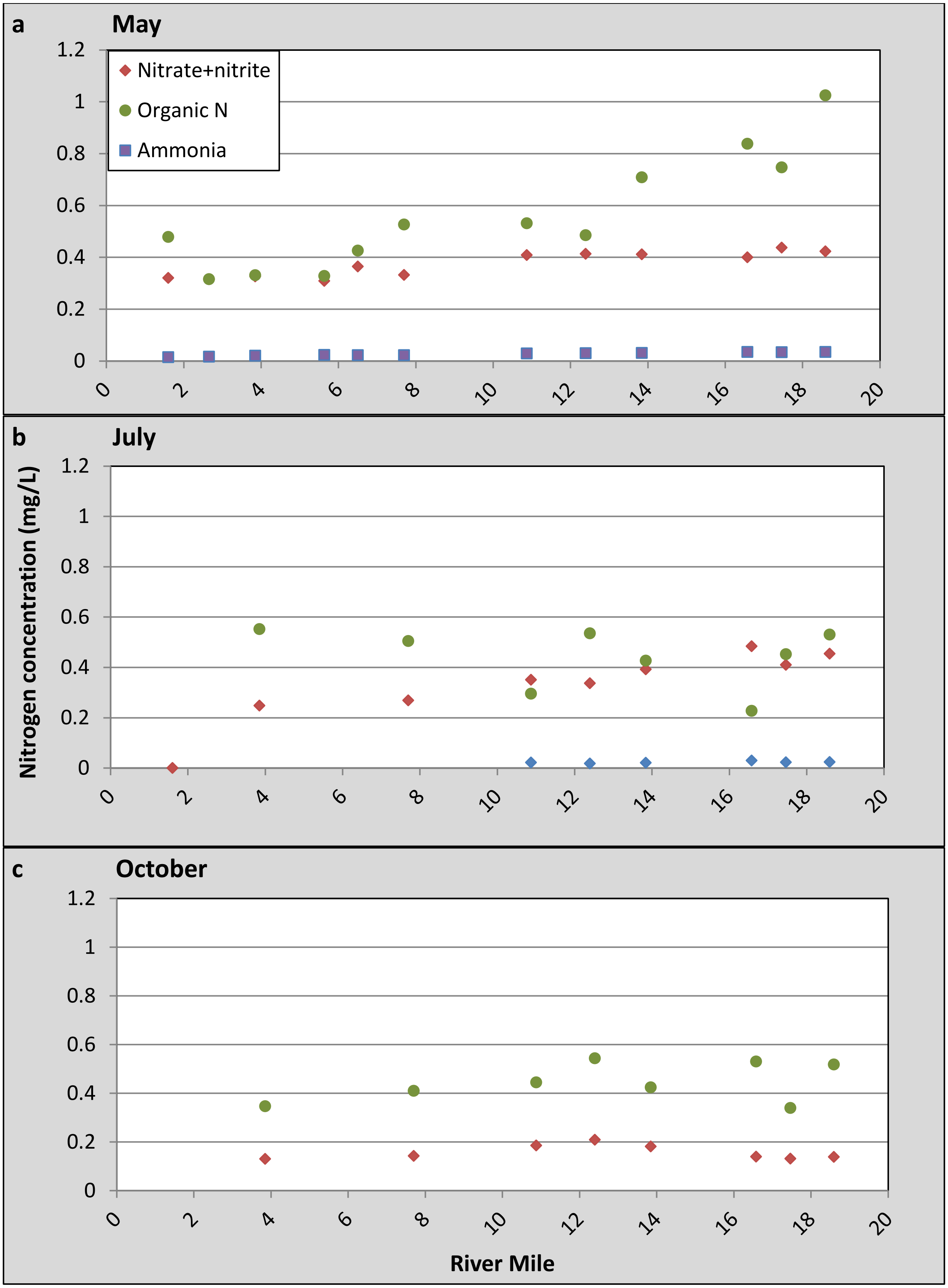
Molar ratios of TN and TP were compared to reported N:P ratios in manure. The TN:TP values at the head of the stream (BG 3) and near the confluence with SBC (BG 14) are reported in Table III. Researchers have found that the ratio of N to P in cattle manure ranges approximately from 3:1 to 5:1 (Toth et al., 2006, Sacco et al., 2003). However, lower observed nitrogen fractions in manure have been attributed to ammonia volatilization and delayed mineralization of organic nitrogen (Beegle et al., 1996). The TN:TP ratios in May and October fall within the range expected from cattle manure.

Table III. TN:TP molar ratios and standard deviations for each sampling event.

Sampling event	TN:TP (mole N/mole P)	
	BG 5	BG 14
May	4.5:1	4.3:1
July	5.7:1	2.8:1
October	4.2:1	3.4:1

3.5. Nitrogen Speciation

Using the Hach DR-6000, samples were analyzed for TN, TKN, NO_3^-/NO_2^-, and NH_3. The speciation of nitrogen was measured to be used as a tool for identifying sources. This data is shown in Figures 15 a, b, and c. In May, the greatest fraction of nitrogen was TKN. A consistent increase of TKN was observed from river mile 6.5 through the rest of the stream. Nitrate/nitrite concentrations increased at lesser rate, but the rate was consistent. A strong positive relationship between ammonia concentration and river mile was observed from upstream to downstream (r^2= 0.96). TKN was the main driver of the TN concentration increase in May. In July, TKN concentrations were significantly lower than the May concentrations, and did not increase significantly over the course of the stream. The nitrate/nitrite concentrations followed a similar pattern to the May data; a slight but consistent concentration increase. July ammonia levels were lower than those observed in May, and did not significantly increase from upstream to downstream. In October, TKN and nitrate/nitrite concentrations reached a minimum (compared to May and July) and did not change significantly throughout the stream length. All measured ammonia concentrations from the October samples were below the reporting limit of 0.015 mg/L. The following three graphs show the nitrogen speciation. The October graph does not contain the ammonia data since it was below the reporting limit.



Figures 15 a, b, c. Nitrogen species concentrations from upstream to downstream, during each sampling event.

3.6. TKN, NO_3^-/ NO_2^-, and TP Concentration Comparison

TKN, NO_3^-/ NO_2^-, and TP concentrations were compared in each sampling event. The data shows that TKN concentrations are generally independent of NO_3^-/ NO_2^- and TP concentrations. However, the linear regressions for TKN and TP were nearly identical in May, both with high r^2 values. The trends for NO_3^-/ NO_2^- and TP vary similarly between months. All linear equations and coefficients of determination are listed in Table IV.

Table IV. Trendline equations and coefficients of determination for TKN, NO_3^-/NO_2^-, and TP concentrations from upstream to downstream for each sampling event.

Sampling Month	TKN	NO$_3^-$/NO$_2^-$	TP
May	0.03x + 0.25 r^2=0.80	0.01x + 0.30 r^2=0.83	0.03x + 0.19 r^2=0.97
July	-0.01x + 0.53 r^2=0.07	0.02x + 0.17 r^2=0.88	0.03x + 0.25 r^2=0.87
October	0.007x + 0.37 r^2=0.20	0x + 0.16 r^2=0	0.01x + 0.25 r^2=0.69

Figures 16 a, b, and c, reinforce that TKN concentrations are highest in the spring, nitrate/nitrite concentrations are fairly constant through the summer, and TP concentrations increase over the stream length in the summer. All concentrations decrease in the fall, and follow a similar pattern; generally increasing until river mile 13.8, (BG 11), and then leveling out.

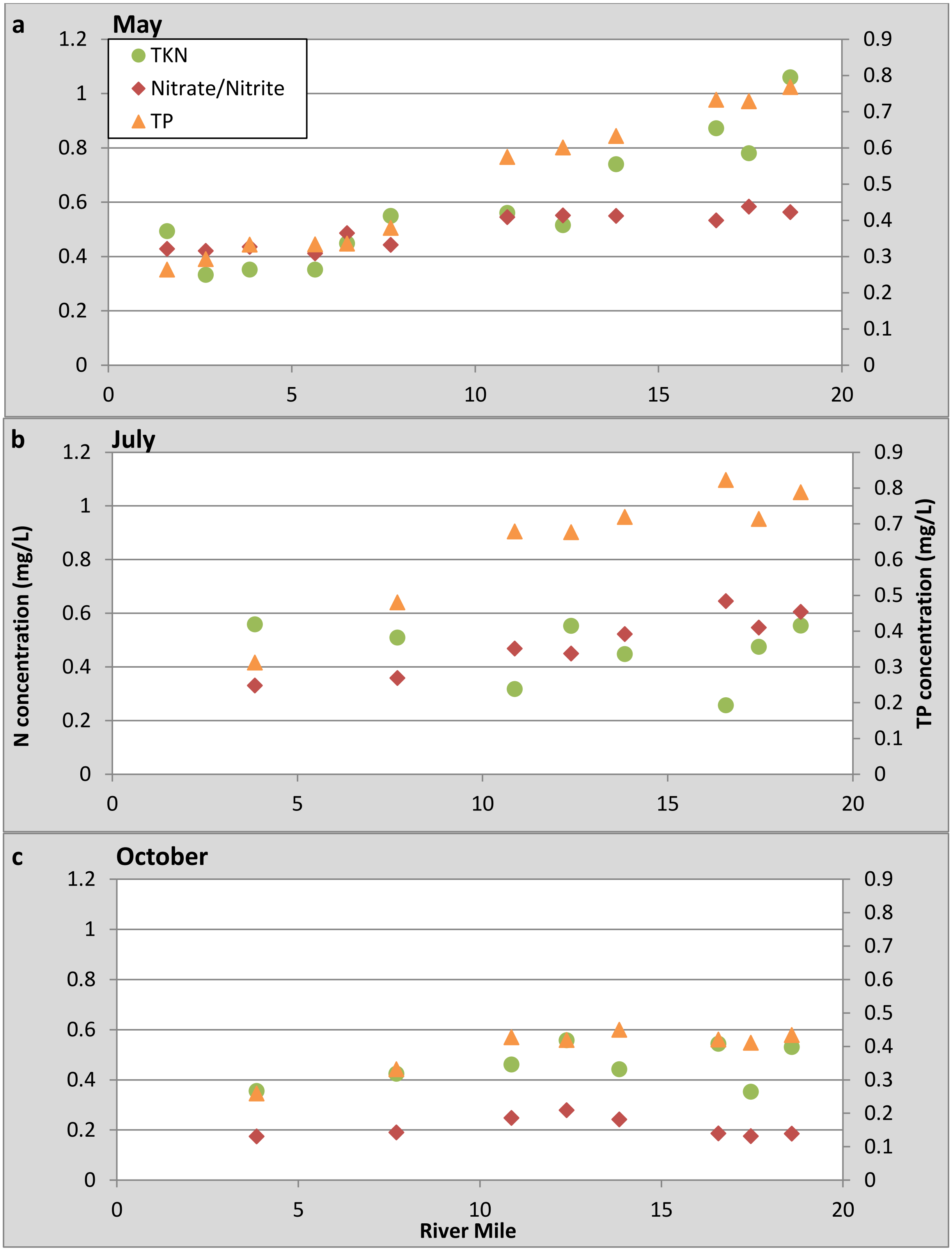


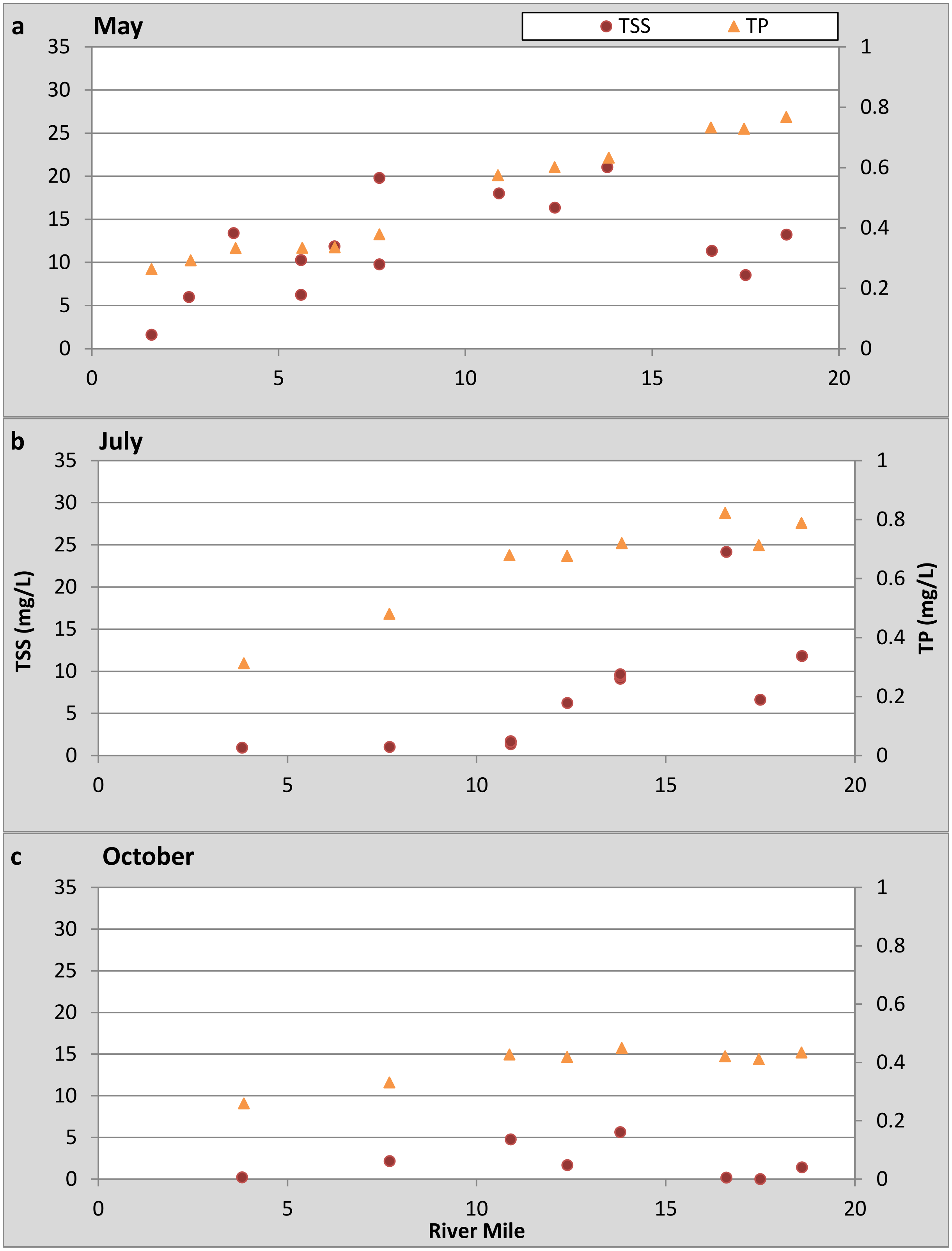
Figure 16 a, b, c. Total Kjeldahl nitrogen, and total phosphorus concentrations during each sampling event.

3.7. Phosphorus, TSS, Alkalinity, Specific conductivity

Phosphorus concentrations were compared with total suspended solids (TSS), alkalinity, and specific conductivity measurements. The comparison between TSS and TP was used to test the hypothesis that highly adsorptive phosphate molecules were being transported via suspended sediment. This data is shown in Figures 17 a, b, and c. TSS was present in the greatest concentration in May during spring runoff, as shown in Figure 17 a. At BG 11 (river mile 13.8), the TSS concentration decreases significantly, while the TP concentration increases. The decrease in TSS corresponds with a decrease in flow rate and turbulence at that point. This data suggests that the TP is not physically or chemically bound to particulate in May. However, the July data exhibits a statistically significant correlation between TP and TSS concentrations. The correlation coefficients and associated p-values from a two-tailed test are listed in Table V.

Table V . Correlation coefficients for comparison of total phosphorus and total suspended solids.

Total phosphorus and total suspended solids	
Sampling Event	*Correlation coefficient*
May, n=12	0.456, $p<0.15$
July, n=8	0.729, $p<0.05$
October, n=8	0.502, $p<0.25$



Figures 17 a, b, c. Total suspended solids and total phosphorus concentrations.

It is unlikely that TP is bound to suspended particulate matter, therefore the hypothesis that groundwater contributes TP was tested. Groundwater alkalinity has been used as a tracer to determine groundwater contributions to surface water (Siegel and Glaser, 1978). The comparison between TP and alkalinity showed a statistically significantly correlation in each sampling dataset. Table VI shows the correlation coefficients and the associated p-values from a two-tailed test.

Table VI. Correlation coefficients for comparison of total phosphorus and alkalinity.

Total phosphorus and alkalinity	
Sampling Event	*Correlation coefficient*
May, n=12	0.98, $p<0.005$
July, n=8	0.89, $p<0.005$
October, n=8	0.87, $p<0.005$

The average alkalinity and TP concentrations from each sampling event were compared, and are shown in Table VII. The May concentrations of both alkalinity and TP are less than the July concentrations. This data suggests that the groundwater contribution is diluted during the spring, possibly due to runoff. This data is displayed graphically in Figure 18.

Table VII. Sampling event averages and standard deviations of alkalinity and total phosphorus concentrations.

Sampling Event	**Alkalinity (mg/L)**		**TP (mg/L)**	
	Average	*ST DEV*	*Average*	*ST DEV*
May, n=12	56.2	25.6	0.50	0.2
July, n=8	82.5	26.6	0.65	0.2
October, n=8	73.8	17.1	0.39	0.1

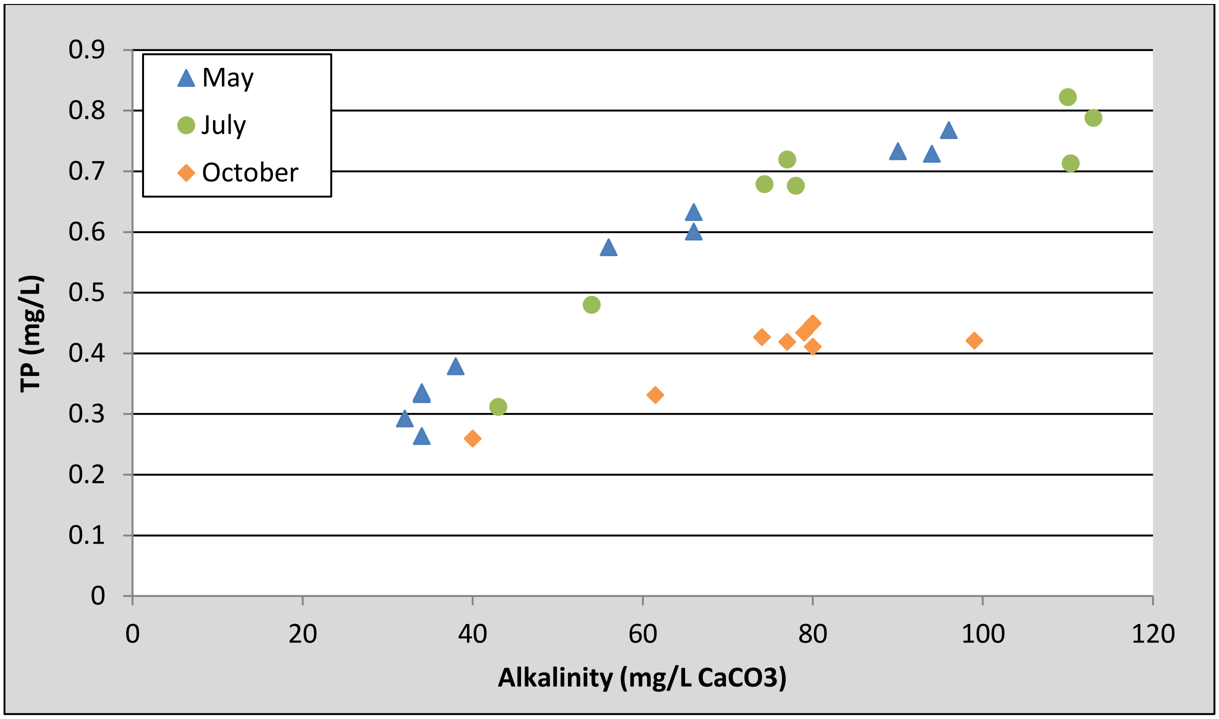


Figure 18. Total phosphorus and alkalinity in May, July, and October, 2014.

The comparison between TP and specific conductivity (SC) was a second method to test the hypothesis that the stream TP concentrations are influenced by groundwater. This data is displayed in Figure 19. A positive correlation was observed in May, July, and October. This data supports the hypothesis that groundwater is a contributing source of phosphorus. The correlations in Table VIII were calculated in Excel and the associated p-levels were determined using a two-tailed analysis.

Table VIII. Correlation coefficient for comparison of total phosphorus and specific conductivity.

Total phosphorus and specific conductivity	
Sampling Event	*Correlation coefficient*
May, n=12	0.94, $p<0.005$
July, n=8	0.84, $p<0.010$
October, n=8	0.76, $p<0.050$

Similar to the alkalinity and TP data comparison, the average SC concentrations were lower in May, than in July, as shown in Table IX. This data suggests that groundwater inputs are diluted in the spring.

Table IX. Sampling event averages and standard deviations of specific conductivity and total phosphorus concentrations.

Sampling Event	SC (µS/cm)		TP (mg/L)	
	Average	*ST DEV*	*Average*	*ST DEV*
May, n=12	136.8	66.3	0.50	0.2
July, n=8	169.5	68.4	0.65	0.2
October, n=8	151.6	47.9	0.39	0.1

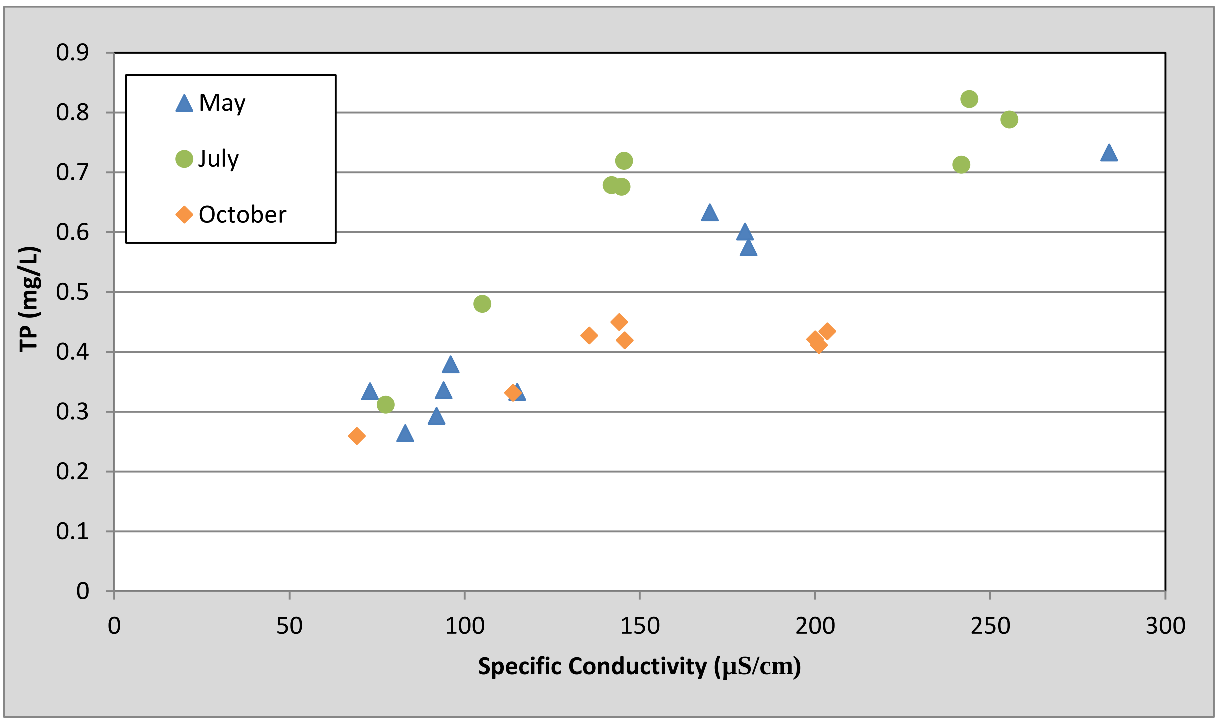


Figure 19. Total phosphorus and specific conductivity in May, July, and October, 2014.

4. Discussion

4.1. Sources

The data produced from this study was used to identify potential nutrient sources in Browns Gulch. In many cases, nitrogen and phosphorus originate from the same source. However, dissimilarities between measured TN and TP concentrations suggest that that is not entirely true in the Browns Gulch watershed.

4.1.1. TKN, NO_3^-/ NO_2^-, and TP concentration comparison

The TKN trend of indicates that a significant source of TKN exists during the spring months. The similarities in NO_3^-/NO_2^- and TP trends suggest that these species, at least partially, originate from the same source (Figures 16 a, b, c).

At river mile 6.5 (BG 7), organic nitrogen concentrations began to increase at a consistent rate in spring (Figure 16 a). Inorganic N increased slightly, but at a significantly depressed rate. BG 7 is located downstream of the first property used specifically for agricultural grazing. The July and October data did not exhibit the same increase in TKN (Figures 16 b, c). It is predicted that the source of TKN is manure; the patterns of TKN concentrations are consistent with those of manure in the riparian area. Manure is deposited on grazed riparian areas throughout the winter months. During spring runoff, organic matter from decomposing manure and other biomass is transported to the stream. Two causes of the notable decrease in TKN from May to July is likely the result of multiple factors. The source material is limited; most manure is flushed off the fields during overland flow events. By July, the warm temperatures may have encouraged the mineralization of some organic N to ammonium.

Flood irrigation is practiced throughout much of the agricultural land in the upper watershed. Flood irrigation functions similar to overland flow runoff, and serves as a mode of nutrient transport from the upper riparian area to the creek. It is hypothesized that NO_3^-/NO_2^- and TP are contributed to the creek via overland flow through agricultural fields in May and July. Since NO_3^-/NO_2^- is highly soluble, it does not accumulate in the winter. Consistent grazing during spring runoff and summer irrigation seasons likely contributes the majority of the inorganic nitrogen.

When irrigating ceases in the fall, the NO_3^-/NO_2^- and TP patterns become dissimilar (Figure 16 c). The October TP concentrations remained fairly constant throughout the stream length, whereas NO_3^-/NO_2^- concentrations decreased. Considered together, it is hypothesized that a fraction of the TP originated from agricultural land practices, and another fraction originated from a different source. The main source of NO_3^-/NO_2^- appears to be from agriculture. The lowest inorganic nitrogen concentrations were observed in October, and were significantly less than the May and July concentrations (Figure 16 c).

Figure 20 qualitatively displays the correlation between land-use and May TN loads. A 250 m buffer was utilized to display land-use adjacent to the stream. Within this buffer, land-use was designated into two categories: forest land and agricultural land. The load gradient categories and the associated colors represent the load measured at the downstream end of the reach.

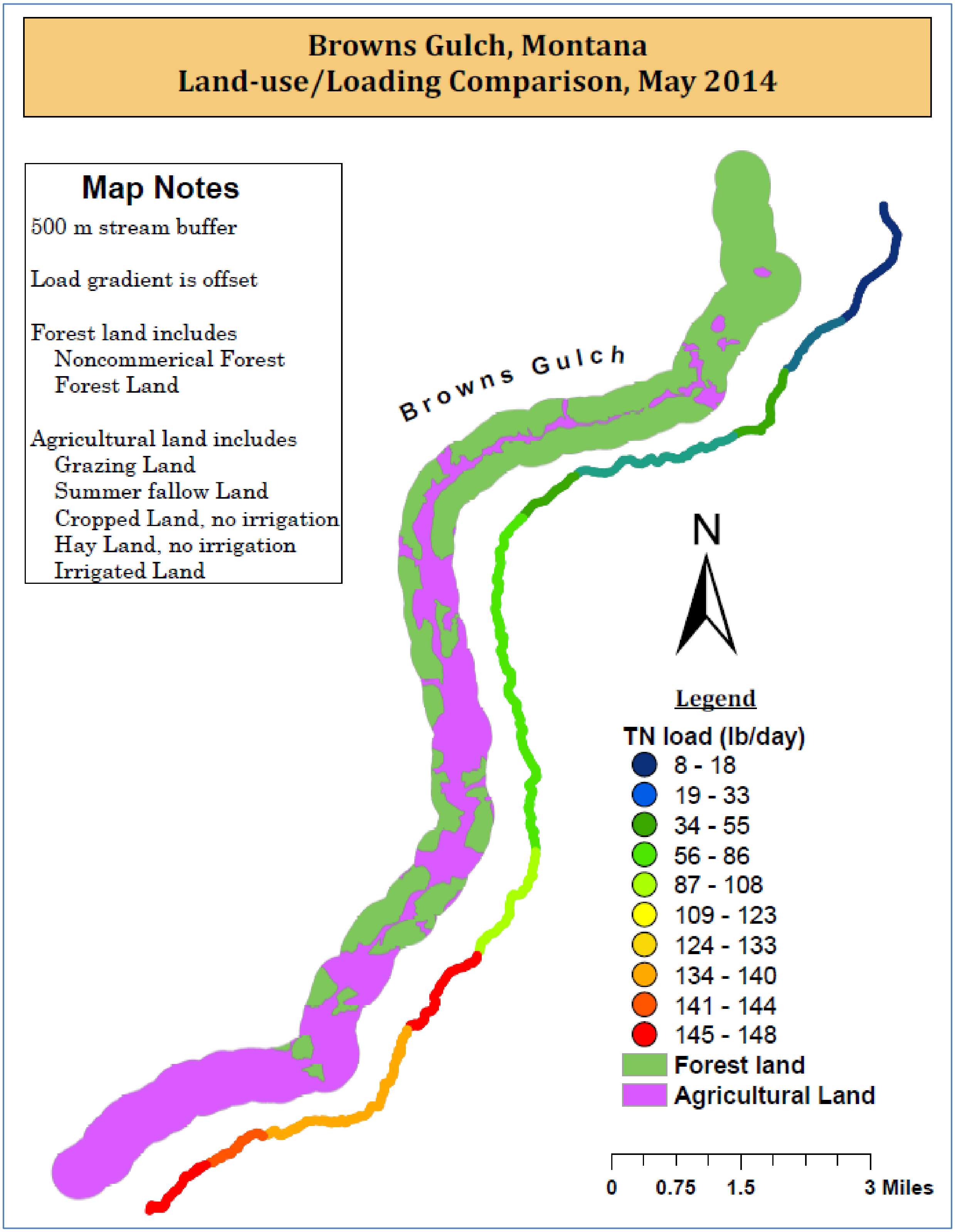


Figure 20. Land-use in a 500 m buffer bounding Browns Gulch and the offset May, 2014 load gradient.

4.1.2. N:P ratios

The measured molar ratios of TN to TP were within the expected range found in livestock manure in May and October. Since many unmeasured factors affect N and P transport from the agricultural land to the stream, this data is largely inconclusive. However, it shows that stream TN to TP ratios do not change significantly from spring to fall, but that phosphorus concentrations increase at a greater rate than do nitrogen concentrations (Table III). This data could suggest that the sources are the same throughout the year. Additionally, the data suggests that nitrogen and phosphorus have different primary sources.

4.1.3. Phosphorus, TSS, alkalinity, specific conductivity

TP concentrations were highly correlated with alkalinity and specific conductivity in all three sampling events (Tables VI, VIII). Such correlations are often indicative of groundwater additions to surface water (Fraser and Williams, 1998). Analysis of the ratio of inorganic nitrogen to total phosphorus suggests that a consistent TP source, which differs from the primary TN source, exists (Table III). Additionally, alkalinity, specific conductivity, and TP concentrations were all diluted during spring runoff (Tables VII, IX). Relatively high TP concentrations (compared to the MT numeric nutrient criteria standard) in the upper watershed indicate that the primary source is likely natural rather than anthropogenic (Figure 13). This hypothesis is consistent with a MTDEQ study, which predicted that phosphorus levels would be higher in Browns Gulch due to the Lowland Creek Volcanic formation (Suplee and Schmidt, 2013). Unpublished field work completed by Scarberry identified small faults within the "Tat" volcanic geologic region (Scarberry, 2014). Faults promote physical and chemical weathering, and therefore create a route for phosphorus to leach into groundwater. Analysis of well logs from the MBMG GWIC database indicates that the Browns Gulch aquifer is primarily unconfined, and it is likely that Browns Gulch is a gaining stream during certain periods. October flow rates increased throughout the stream length though many of the tributary streams were dry (Figure 10).

4.2. Selected BMPs

BMPs for the minimization of agricultural sources of TN and TP were investigated, with the goal of determining the most suitable strategies for the sources and land-use practices in Browns Gulch.

In Browns Gulch, the main source of TN and a supplemental source of TP is agricultural land-use. Cattle grazing in the riparian area and flood irrigation are the likely agricultural practices contributing to excess nutrients. Continuous grazing of riparian areas has been linked to increased suspended sediment, TKN, and total organic carbon levels in streams (Owens et al., 1989). A variety of applicable agricultural BMPs are listed in Table X, along with their associated N and P load reduction percentages. Of the BMPs investigated, off-stream water sources, and the combination of exclusion fencing and woody vegetation in the riparian area, provide the greatest nutrient load reductions.

Table X. Nitrogen and phosphorus load reductions from agricultural BMPs.

BMP	Nitrogen reduction (%)	Phosphorus reduction (%)
Vegetated filter strip[1,2]	>50	>50
Off-stream water source[3]	54	81
Exclusion fencing[4]	21-52	32-34
Exclusion fencing + woody vegetation[5]	55.2*	78.5

1: EPA, 2005, 2: Grismer et al., 2006, 3: Sheffield et al, 1997, 4: Miller et al., 2010, 5: Line et al., 2000, *: TKN-N reduction.

4.2.1.1. Vegetated Filter Strips

The use of vegetated filter strips (VFS) in Browns Gulch is one plausible treatment BMP. Key considerations for a VFS are width of the strip and vegetation type. On flatter areas, a 10-15 ft filter area has been shown to reduce N and P concentrations by approximately 50% (Grismer et al., 2006). Greater slopes require greater filter widths for the same pollutant removal. However, this treatment is not significantly effective at slopes greater than 15% (Grismer et al., 2006). Therefore, specific land characteristics would have to be determined before recommending VFS use and/or width specifications for Browns Gulch. Acceptable native vegetation for the lower montane riparian shrubland should be a combination and shallow and deep native grasses, and/or woody vegetation, such as willows, alder, and redosier dogwood (Agouridis et al., 2005, Vance et al., 2010).

Figure 21 shows a Browns Gulch property where a VFS could be implemented. This photo is representative of the smaller agricultural properties along Browns Gulch. The riparian area is relatively flat, therefore a 15 ft VFS could be effective. The flat property area is wide enough to accommodate both livestock grazing and a VFS. Additionally, the VFS would promote bank stability and reduce sediment loads from erosion.

Figure 21. Browns Gulch agricultural property with VFS potential.

4.2.1.2. Off-stream water source

In Browns Gulch, livestock use the stream as the primary water source. Sheffield et al. (1997) found that with the introduction of an off-stream water trough, cattle usage of the stream significantly decreased, even without exclusionary structures. Concentrating cattle grazing further from the riparian area contributed to the decrease in N and P loads to the stream. A side-benefit to off-stream water source is improved cattle health and productivity (Zeckoski et al., 2012). Additional design criteria to encourage cattle grazing on higher ground includes providing shade, planting palatable forage species, and addition of salt and mineral in the designated grazing location (Agouridis et al., 2005). Many upland areas in Browns Gulch have juniper stands, which have the capacity to provide plenty of shade. An off-stream water source would be a good option for many of the agricultural properties on Browns Gulch.

Figure 22 shows a Browns Gulch property that is representative of the larger agricultural operations along BG. An important component of the effectiveness of off-stream water sources is the availability of shade for the livestock (Line et al., 2000). Most of the lightly grazed areas in Browns Gulch are populated with juniper trees. Landowners have stated that cattle often rest beneath these trees. Installation of an off-stream water source would allow cattle to graze on the land above the riparian area, and cool off in the shade instead of the creek. This photo exhibits an obvious lack of vegetative diversity and woody vegetation adjacent to the creek. Reducing the cattle’s heavy use of the riparian area would provide time for vegetation to take root and regenerate along the stream banks.

Figure 22. Browns Gulch agricultural property with off-stream water potential.

4.2.1.3. Exclusion fencing

Exclusion fencing is one of the most effective and common BMPs to reduce sediment, N and P loads to surface water (Agouridis et al., 2005, Line et al., 2000). Unfortunately, studies have shown that landowners often choose other options due to the high cost of fencing. The United States Department of Agricultural provides Environmental Quality Incentive Program (EQIP) grants to fund riparian fencing projects. Exclusion fencing is often used in conjunction with VFS and off-stream water sources, but not always. One study found that the vegetation in the excluded area increased by three times, without any additional treatments (Scrimgeour and Kendall, 2003). The Virginia Department of Conservation and Recreation found that, with government tax-credits, a landowner could install fencing, off-stream water sources, and designated stream crossings for $2300 (Zeckoski et al., 2012). This option is reasonable for some of the larger cow-calf operations in Browns Gulch.

Figure 23 shows the negative impacts of heavy grazing on stream bank stability. Installation of exclusion fencing on broad, flat properties like the one shown below would greatly benefit the stream quality. The addition of stabilized cattle crossings and concentrated stream access points would reduce the cattle's impact, while allowing them to pass from one side of the creek to the other. Another benefit of the exclusion fencing would be increased vegetative diversity. Non-native, short-rooted grasses are the dominant species in much of the riparian area, as is shown in Figure 23.

Figure 23. Browns Gulch agricultural property with exclusion fencing potential.

4.2.1.4. Potential results in Browns Gulch

Implementation of either VFSs, an off-stream water source, or exclusion fencing could reduce TN and TP loads in Browns Gulch. Table XI lists estimated TN loads after implementation of a single BMP. The asterisk indicates that the estimated load is less than the TMDL load allocation. These estimates assume that 100% of the nitrogen load is originating from agricultural sources and that a 50% reduction is achieved. It is also assumed that all agricultural properties implement one of the three BMPs. A quantitative estimate of TP load reductions is not possible because the fraction of phosphorus originating from agricultural sources in unknown. However, these BMPs would reduce the TP load from agricultural land-uses to some degree.

Table XI. Potential total nitrogen loads reductions from BMPs.

Month	**Potential TN load contributed to SBC (lbs/day)**
May	74
July	4*
October	5*

5. Conclusions

5.1. TN and TP Loading

The first objective of this study was to determine nutrient loads in Browns Gulch, both temporally and spatially. In all seasons, TN and TP loads increased from the head of the stream to river mile 12.4 (BG 10). Directly downstream of this sampling location, a diversion dam redirected water for agricultural uses, causing load decreases. In May, the maximum TN load was 147.7 lbs TN/day and was measured at river mile 18.6 (BG 14) near the confluence with SBC. The maximum TP load, 84.4 lbs/day was recorded at river mile 17.5 (BG 13), however the load contribution from Browns Gulch to SBC was 76.6 lbs/day. During July and October, maximum TN and TP loads were measured at BG 10, but the load contributions to SBC were much lower. In July and October, when TMDLs apply, TN load contributions to SBC were 8.2 and 10.3 lbs/day, respectively. These loads slightly exceed the TMDL load allocation of 7.0 lbs/day. In July and October, TP load contributions to SBC were 6.4 and 6.7 lbs/day, respectively. These loads greatly exceed the TMDL load allocation of 0.7 lbs/day.

5.2. TN and TP Sources

Anthropogenic and natural sources are contributing nutrients to Browns Gulch. The primary source of TN is most likely agricultural land-use, specifically cattle grazing in the riparian area. The two main sources of TP appear to be agriculture land use and surficial geology.

In May, organic nitrogen was the main nitrogen species in the stream and was likely from manure and decaying organic matter deposited throughout the riparian zone. In May and July, steady levels of nitrate/nitrite were contributed to the stream from grazed areas via spring runoff and summer flood irrigation.

A consistent TP load, in all seasons, likely entered the stream from groundwater, which may contain chemical constituents from dissolved volcanic rock. In May and July, manure and degrading organic matter appear to have contributed TP to the stream during spring runoff and summer flood irrigation.

5.3. BMPs

The primary load source of TN and supplementary load source of TP is believed to be agricultural; therefore, BMPs will be specifically targeted to address agricultural land-use practices. BMPs were investigated individually and together, and were based on case-studies and models developed by other researchers. The best option for reducing N and P loads from agricultural land uses would be installation of exclusion fencing, the creation of a 15 ft vegetated buffers strip, and the installation of an off-stream water source. However, this combination of BMPs may be economically unfeasible to many landowners.

Implementation of one of the three proposed BMPs has the potential to reduce the May, July, and October TN load contributions from Browns Gulch to SBC to 74, 4, and 5 lbs/day, respectively. The growing season (July 1 through September 30) is the target period for TMDL load limitations. Therefore, any of the three proposed BMPs would sufficiently reduce the July TN loads to below the Browns Gulch load allocation of 7 lbs/day.

Hail Columbia Gulch is the most significant tributary to Browns Gulch, and is grazed heavily year-round. Recommended BMPs for Browns Gulch are applicable to Hail Columbia Gulch, and would benefit both streams.

The load source of TP is believed to be primarily natural; therefore, without downstream water treatment, BMPs are not a logical solution to reduce loading. Although, the agricultural sources of TP will be reduced using the BMPs recommended for agricultural land-use.

Quantitatively estimating load reductions is not possible because the fraction of phosphorus originating from agricultural sources in unknown.

Upstream of the Browns Gulch confluence with SBC, the Butte-Silver Bow Wastewater Treatment plant (BSB-WWTP) is a large source of both N and P. Over the next few years, the plant will be completing upgrades, including the installation of a membrane bioreactor following the activated sludge process. These upgrades will greatly reduce the level of phosphorus that is discharged. Therefore, the load reduction from the BSB-WWTP may be able to be allocated to Browns Gulch, to account for the naturally occurring phosphorus load.

6. Future work

This thesis work has identified several items that deserve further study.

6.1. Field Measurements

Measurement of flow rates above and below tributary inlets, and in the tributaries would be useful for the development of a water balance. Collection of samples from tributaries would provide enough data to develop a TN and TP mass balance that accounts for contributions from these sources. Groundwater well sampling, within the floodplain and throughout the watershed, would provide data to better understand the contribution of TP from geologic/groundwater sources. Limited water quality data for this watershed is currently available from the Montana Bureau of Mines and Geology's Groundwater Information Center (GWIC); however, more well data may be available in the future.

6.2. Laboratory Measurements

For further investigation into longitudinal and spatial variations in nitrogen speciation, the use of a flow injection analyzer is advised. This instrument has a lower limit of detection and lower reporting limit than the Hach DR-6000 spectrophotometer. Measurement of soluble reactive phosphorus (SRP) to TP ratios could provide additional qualitative data to determine the extent to which volcanic geology is contributing to stream phosphorus levels. Higher SRP:TP ratios are expected in volcanically influenced water, and are characteristic of different volcanic formations (Suplee and Schmidt, 2013). Measurement of stream silicon dioxide levels could provide more information about the potential volcanic geology source. Si is often concomitant with P from the erosion of volcanic rocks.

6.3. Data processing

Nutrient contributions from septic systems were not thoroughly investigated in this study. Recently, an ArcGIS tool was cooperatively developed by the Department of Scientific Computing at Florida State University and the Florida Department of Environmental Protection (Rios et al., 2013). The program, ArcNLET, is a free toolkit addition for ArcGIS that was designed to estimate nitrate loads from septic systems. Information required for this model exceeded what was collected in this study. Hydraulic conductivity, soil porosity, septic locations, septic system design parameters, and a digital elevation model are required to produce reliable results from this program.

6.4. BMPs

Use of the EPA's "Spreadsheet Tool for Estimating Pollutant Load" (STEPL) model would allow for a better estimate of load reductions from various BMPs. This tool can be used to model the effectiveness of one or more BMPs from many sources. For this model, the following information is required: land-use acreage, population of livestock type, specific watershed-wide septic system information, soil hydrologic group information, N, P, and BOD runoff concentrations from each land-use type, and average N, P, BOD soil concentrations. Specific BMP recommendations from such a model would be useful to watershed conservation groups interested in stream water quality projects.

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Appendix A: Sampling locations and photos

Table A, I. Sampling locations, ownership and GPS coordinates (GCS North America, 1983)

Site ID	River mile	Ownership	Latitude	Longitude
BG 14	18.6	Private	46.005285	-112.700031
BG 13	17.5	Private	46.013635	-112.686523
BG 12	16.6	Private	46.018548	-112.673668
BG 11	13.8	Private	46.037098	-112.640800
BG 10	12.4	Private	46.049855	-112.625065
BG 9	10.9	Private	46.067124	-112.612848
BG 8	7.7	Private	46.107566	-112.625018
BG 7	6.5	Private	46.122470	-112.619083
BG 6	5.6	Private	46.129665	-112.606374
BG 5	3.8	USFS	46.137382	-112.568498
BG 4	2.6	USFS	46.147907	-112.557230
BG 3	1.6	USFS	46.156853	-112.543534

BG 3, river mile 1.6

BG 3 is located on USFS land. The width of the stream in May was 2.7 ft. Sampling was conducted north of the culvert.

Figure A, 1. BG 3 sampling location, pointing south.

BG 4, river mile 2.6

BG 4 is located on USFS land. The width of the stream in May was 6.0 ft. Sampling was conducted at a relatively straight stretch of stream, downstream the confluence with American Gulch.

Figure A, 2. BG 4 sampling location, pointing north.

BG 5, river mile 3.8

BG 5 is located on USFS land. The width of the stream in May was 8.8 ft. The sampling was conducted at an access point between some large willows.

Figures A, 3 a and b. BG 5 sampling location, a is pointing north, b is pointing south.

BG 6, river mile 5.6

BG 6 is located on private property. The width of the stream in May was 6.0 ft. Sampling was conducted at a relatively straight section downstream of the culvert.

Figures A, 4 a and b. BG 6 sampling location, a is pointing north, b is pointing east.

BG 7, river mile 6.5

BG 7 is located on private property. The width of the stream in May was 9.0 ft. Sampling was conducted upstream of a large growth of willows and downstream the confluence with Flume Gulch.

Figure A, 5. BG 7 sampling location, pointing south.

BG 8, river mile 7.7

BG 8 is located on private property. The width of the stream in May was 13.0 ft. This sampling location is downstream the confluence with Telegraph Gulch.

Figure A, 6. BG 8 sampling location, pointing west.

BG 9, river mile 10.9

BG 9 is located on private property. The width of the stream in May was 14.5 ft. The sampling location was on the north side of the bridge and downstream the confluence with Hail Columbia Gulch.

Figure A, 7. BG 9 sampling location, pointing north.

BG 10, river mile 12.4

BG 10 is located on private property. The width of the stream in May was 13.5 ft. the sampling location was on a straight stretch of stream south of the bridge.

Figures A, 8 a and b. BG 10 sampling location, a is pointing south, b is pointing west.

BG 11, river mile 13.8

BG 11 is located on private property. The width of the stream in May was 11.0 ft. The sampling location is downstream of the reinforced streambed crossing and upstream the diversion dam.

Figure A, 9. BG 11 sampling location, pointing west.

BG 12, river mile 16.6

BG 12 is located on private property. The width of the stream in May was 9.2 ft. The sampling location was located east of the road and culvert.

Figure A, 10. BG 12 sampling location, pointing west.

BG 13, river mile 17.5

BG 13 is located on private property. The width of the stream in May was 10.0 ft. The sampling location is between the culvert and the livestock fence.

Figure A, 11. BG 13 sampling location, pointing north.

BG 14, river mile 18.6

BG 14 is located on private property. The width of the stream in May was 11.6 ft. The sampling location was located at a straight stretch, near the southern property border.

Figure A, 12. BG 14 sampling location, pointing south.

Appendix B: Field and Lab QA/QC

Marsh McBirney Flo-Mate 2000

The Marsh McBirney Flo-Mate 2000 was used to measure flow rate in the stream. The sensor was placed in a five gallon plastic bucket of water in the field. The sensor remained at least three inches away from the sides and bottom of the bucket for 10 to 15 minutes while the water settled. Zero stability is ±0.05 ft/sec. Twenty individual stream measurements were collected at equal intervals across the stream channel. The flow sensor was placed at 1/3 the depth. The USGS midsection method was used to calculate the total flow rate.

MS5 Hydrolab multiprobe

The multiprobe instrument was used to measure in-stream water quality parameters and field conditions, which included pH, conductivity, air and water temperature, dissolved oxygen (DO), and barometric pressure. The instrument was calibrated daily in the field, prior to the measurement of the first sample. The pH probe was calibrated using two standard buffers of pH 4 and 7 that produce a two point calibration curve. The conductivity probe was calibrated using two standard solutions of 143 µs/cm and 1413 µs/cm. The DO probe was calibrated using local barometric pressure readings. The Hydrolab was placed gently in a flowing section of the stream. Data was collected after the probes had reached equilibrium with the water, approximately 5 minutes. Between readings, the probes were stored in a pH 4 solution, as per the manufacturer's recommendation.

Hach DR 890 colorimeter

The turbidity cell was calibrated with a 0 Nephelometric Turbidity Unit (NTU) DI water sample and a 100 NTU turbidity standard. Calibration was conducted at each sample site, before sample analysis. Samples were collected directly from the stream using the sample vial. Samples were agitated immediately prior to analysis to reduce measurement error associated with particle settling.

Dionex ICS-2100 Ion Chromatography System

This instrument was operated according to EPA Method 300.0, "*Determination of Inorganic Anions by Ion Chromatography*." A five part serial dilution of a pre-made standard was used to create a five point calibration curve. QA/QC measurements include the following:

Lab Reagent Blank, once at beginning of sample run
Lab Fortified Blank, once at beginning of sample run
Instrument Performance Check, every 10 samples
Calibration Blank, every 10 samples
Lab Fortified Sample Matrix, every 10 samples
Field Duplicate, every 14 samples
Lab Duplicate, every 7 samples

Hach DR 6000 UV-VIS Spectrophotometer

This bench top spectrophotometer was used according to the specific methods indicated for ammonia, total Kjeldahl nitrogen, and total phosphorus. Before sample analysis, an automated internal calibration is completed. For all methods, the Hach Wastewater Effluent Mixed Parameters Inorganics Standard was used for QA/QC.

<u>Total phosphorus</u>: The Hach Method 10210 (Ascorbic Acid Method) was used to determine phosphorus concentrations.

<u>Total Kjeldahl nitrogen:</u> The Hach Method 10242 (Simplified TKN Method) was used to determine TKN concentrations.

<u>Ammonia-nitrogen:</u> The Hach Method 10205 (Salicylate Method) was used to determine ammonia concentrations.

Appendix C: 2014 TN and TP loading comparisons

Table C, I. Total nitrogen and total phosphorus load comparisons, May, 2014.

May 2014		TN				TP			
Site ID	**River Mile**	**Load (lbs/day)**	**Δ from TMDL (lbs/day)**	**% change from upstream reach**	**% change mile**	**Load (lbs/day)**	**Δ from TMDL (lbs/day)**	**% change from upstream reach**	**% change mile**
BG 14	18.6	147.68	+140.6	5	4	76.6	+75.9	-9	-8
BG 13	17.5	141.28	+134.3	1	1	84.4	+83.7	5	5
BG 12	16.6	139.67	+132.6	-5	-2	80.6	+79.9	-1	0
BG 11	13.8	147.24	+140.2	33	23	81.0	+80.4	13	9
BG 10	12.4	111.00	+104.0	4	2	71.7	+71.0	13	8
BG 9	10.9	107.25	+100.2	7	2	63.6	+62.9	47	15
BG 8	7.7	100.41	+93.4	20	16	43.1	+42.5	25	21
BG 7	6.5	83.94	+76.9	67	77	34.6	+33.9	36	41
BG 6	5.6	50.41	+43.4	-16	-9	25.5	+24.8	-14	-8
BG 5	3.8	60.12	+53.1	120	100	29.5	+28.8	140	117
BG 4	2.6	27.28	+20.2	225	214	12.3	+11.6	352	336
BG 3	1.6	8.40	+1.4			2.7	+2.0		

Table C, II. Total nitrogen and total phosphorus load comparisons, July, 2014.

July 2014		TN				TP			
Site ID	**River Mile**	**Load (lbs/day)**	**Δ from TMDL (lbs/day)**	**% change from upstream reach**	**% change mile**	**Load (lbs/day)**	**Δ from TMDL (lbs/day)**	**% change from upstream reach**	**% change mile**
BG 14	18.6	8.17	+1.1	-5	-4	6.4	+5.7	-8	-7
BG 13	17.5	8.59	+1.6	-2	-3	6.9	+6.2	-29	-33
BG 12	16.6	8.80	+1.8	-63	-23	9.8	+9.1	-52	-19
BG 11	13.8	23.52	+16.5	-5	-4	20.2	+19.5	8	6
BG 10	12.4	24.85	+17.8	38	25	18.6	+17.9	2	1
BG 9	10.9	18.00	+11.0	16	5	18.3	+17.6	91	29
BG 8	7.7	15.52	+8.5	88	23	9.6	+8.9	200	52
BG 5	3.8	8.26	+1.2			3.2	+2.5		

Table C, III. Total nitrogen and total phosphorus load comparisons, October, 2014.

October 2014		TN				TP			
Site ID	**River Mile**	**Load (lbs/day)**	**Δ from TMDL (lbs/day)**	**% change from upstream reach**	**% change mile**	**Load (lbs/day)**	**Δ from TMDL (lbs/day)**	**% change from upstream reach**	**% change mile**
BG 14	18.6	10.30	+3.3	-6	-5	6.7	+6.0	-28	-25
BG 13	17.5	10.98	+3.9	1	1	9.3	+8.6	39	44
BG 12	16.6	10.84	+3.8	-6	-2	6.7	+6.0	-20	-7
BG 11	13.8	11.57	+4.5	-12	-8	8.3	+7.6	16	11
BG 10	12.4	13.11	+6.1	39	26	7.2	+6.5	15	10
BG 9	10.9	9.42	+2.4	69	22	6.2	+5.5	91	29
BG 8	7.7	5.56	-1.5	294	76	3.2	+2.6	340	88
BG 5	3.8	1.41	-5.6			0.7	+0.0		

Appendix D: TN:TP data

Table D, I. Average TN:TP molar ratios over the entire stream length for each sampling event.

Sampling Month	Average TN:TP (mole/L / mole/L)	Standard deviation
May	4.51:1	0.95
July	3.08:1	1.17
October	3.51:1	0.52

Table D, II. Average TN:TP mass ratios over the entire stream length for each sampling event.

Sampling Month	Average TN:TP (mg N/mg P)	Standard deviation
May	2.04:1	0.95
July	1.39:1	1.17
October	1.59:1	0.52

Table D, III. Average TN:TP mass ratios at BG 5 and BG 14 for each sampling event.

Sampling event	TN:TP (mg N/mg P)	
	BG 5	*BG 14*
May	2.0:1	1.9:1
July	2.6:1	1.3:1
October	1.9:1	1.5:1

Appendix E: Observed 2014 stream flows

Table E, I. Measured stream flows for May, 2014

Date	5/30/2014		
River Mile	**Site ID**	**Discharge (cfs)**	**+/-**
18.6	BG 14	18.51	0.93
17.5	BG 13	21.49	1.07
16.6	BG 12	20.40	1.02
13.8	BG 11	23.75	1.19
12.4	BG 10	22.12	1.11
10.9	BG 9	20.51	1.03
7.7	BG 8	21.12	1.06
6.5	BG 7	19.11	0.96
5.6	BG 6	14.15	0.71
3.8	BG 5	16.45	0.82
2.6	BG 4	7.80	0.39
1.6	BG 3	1.91	0.10

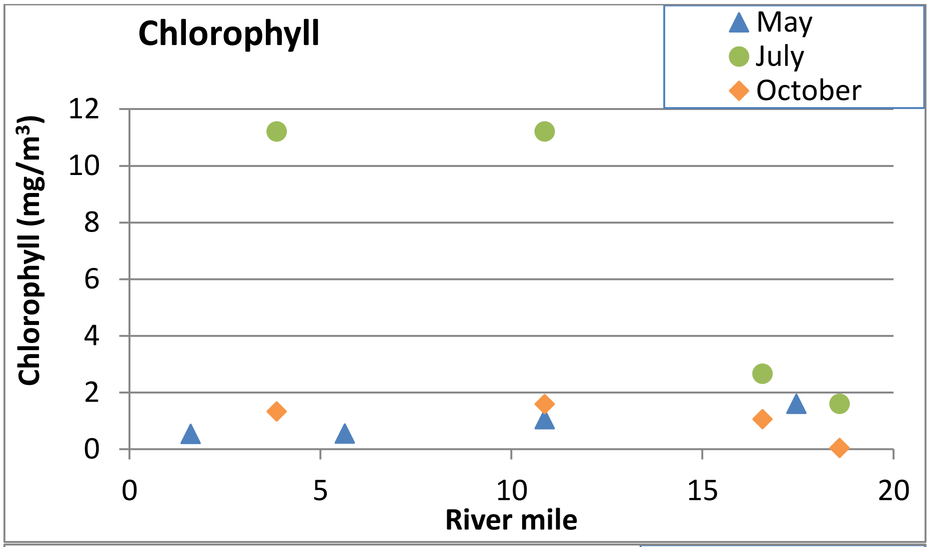
Table E, II. Measured stream flows for July, 2014.

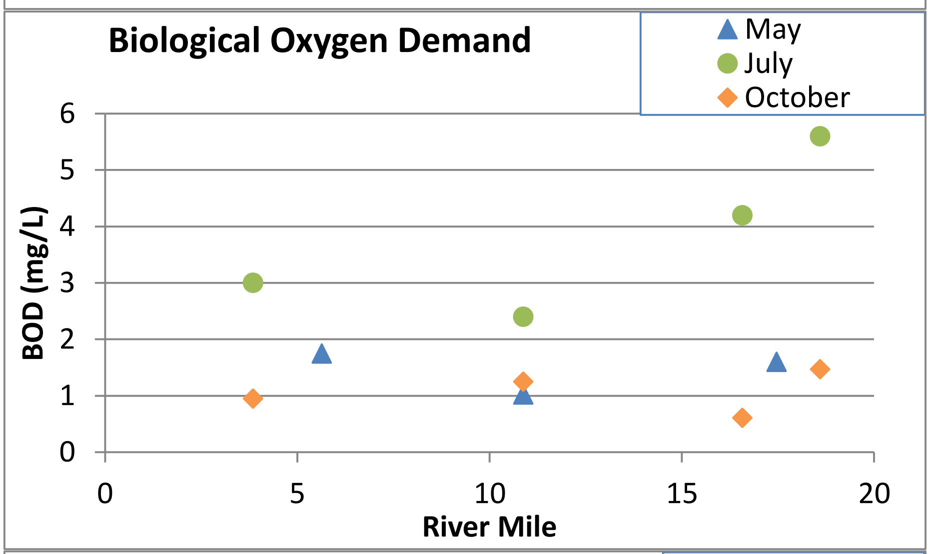
Date	7/23/2014		
River Mile	**Site ID**	**Discharge (cfs)**	**+/-**
18.6	BG 14	1.50	0.08
17.5	BG 13	1.80	0.09
16.6	BG 12	2.20	0.11
13.8	BG 11	5.20	0.26
12.4	BG 10	5.10	0.26
10.9	BG 9	5.00	0.25
7.7	BG 8	3.70	0.18
3.8	BG 5	1.90	0.10

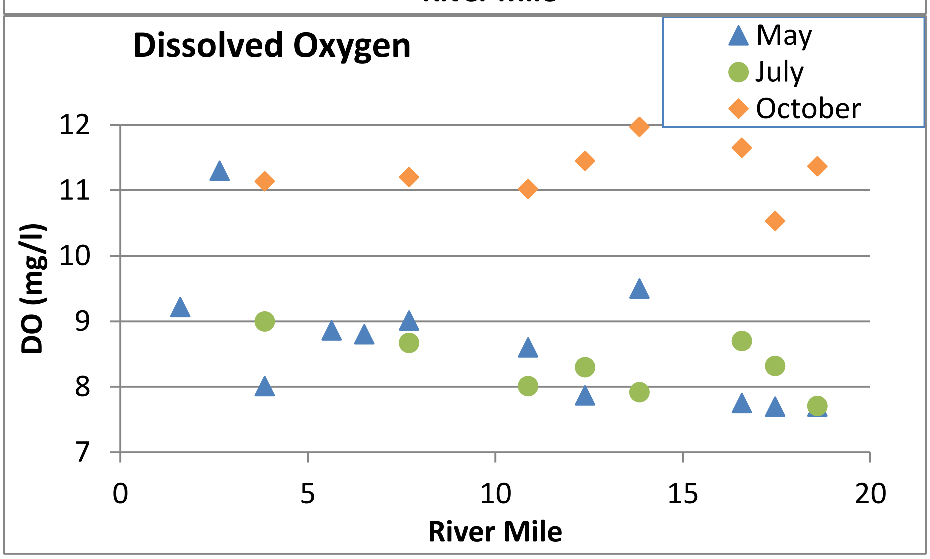
Table E, III. Measured stream flows for October, 2014.

Date	10/27/2014		
River Mile	**Site ID**	**Discharge (cfs)**	**+/-**
18.6	BG 14	2.86	0.14
17.5	BG 13	4.20	0.21
16.6	BG 12	2.94	0.15
13.8	BG 11	3.44	0.17
12.4	BG 10	3.17	0.16
10.9	BG 9	2.70	0.14
7.7	BG 8	1.82	0.09
3.8	BG 5	0.53	0.03

Appendix F: DO, BOD, Temperature, and Chlorophyll data







Appendix G: TN and TP loading maps

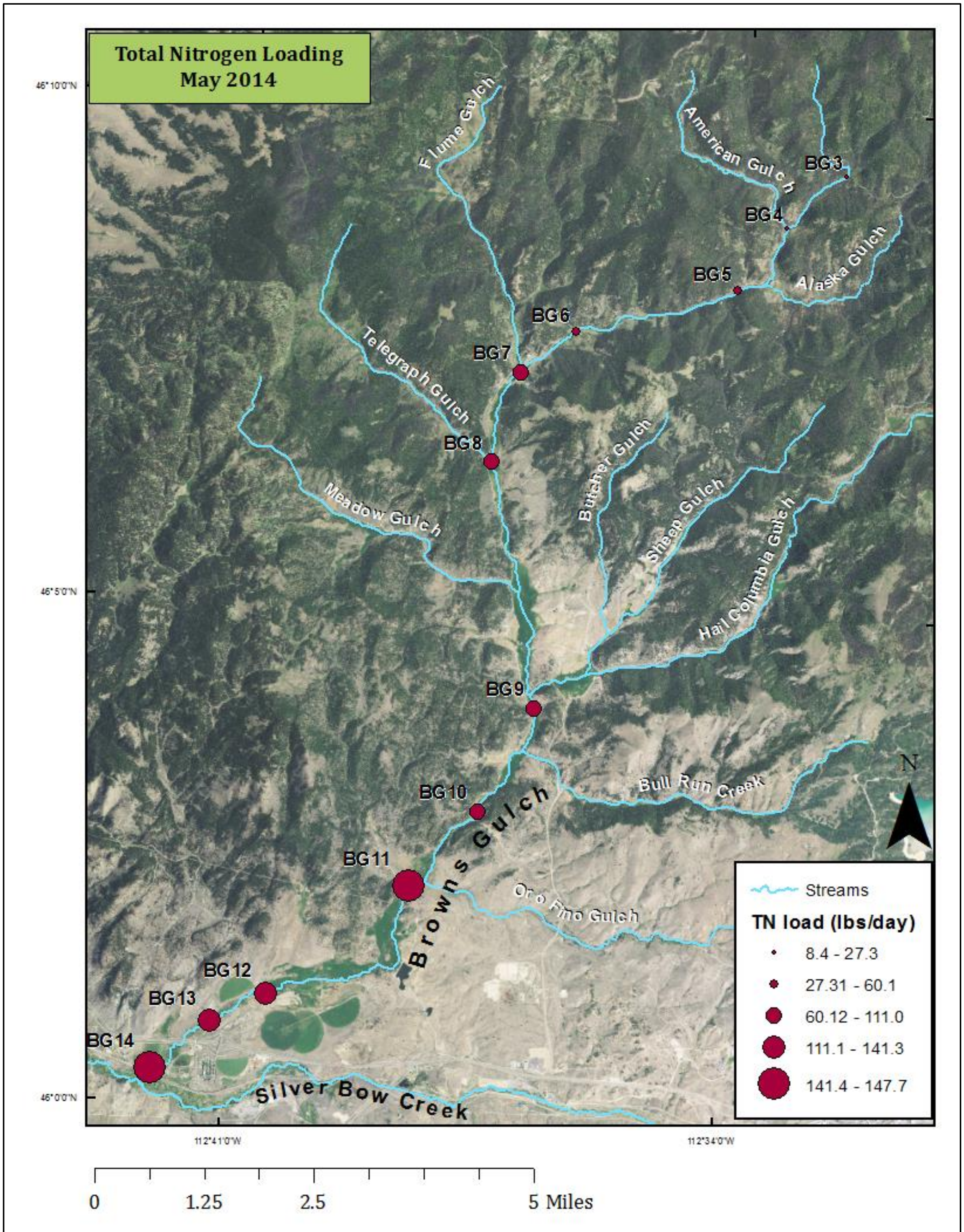


Figure G, 1. Total nitrogen loading represented with graduated symbols for May, 2014.

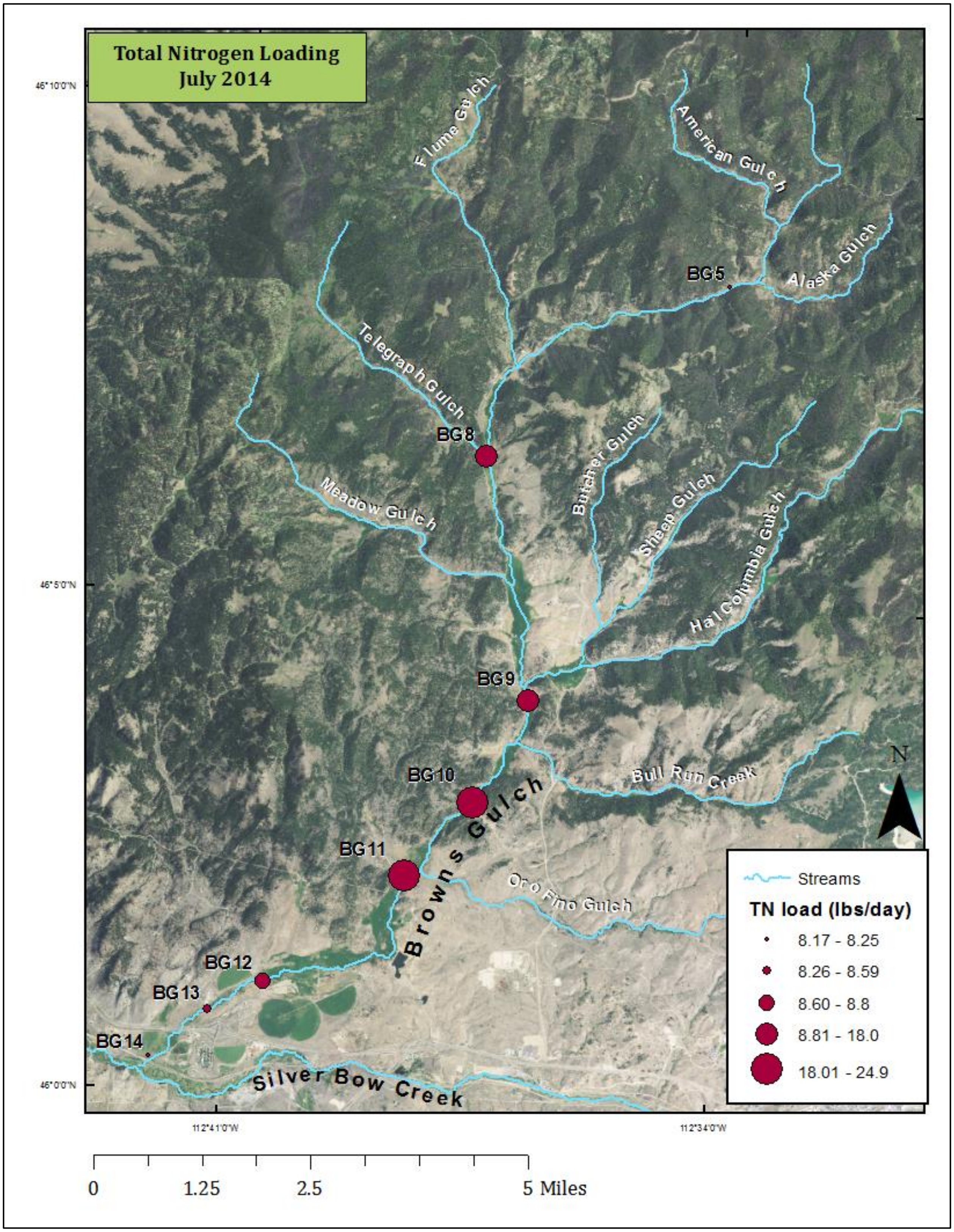


Figure G, 2. Total nitrogen loading represented with graduated symbols for July, 2014.

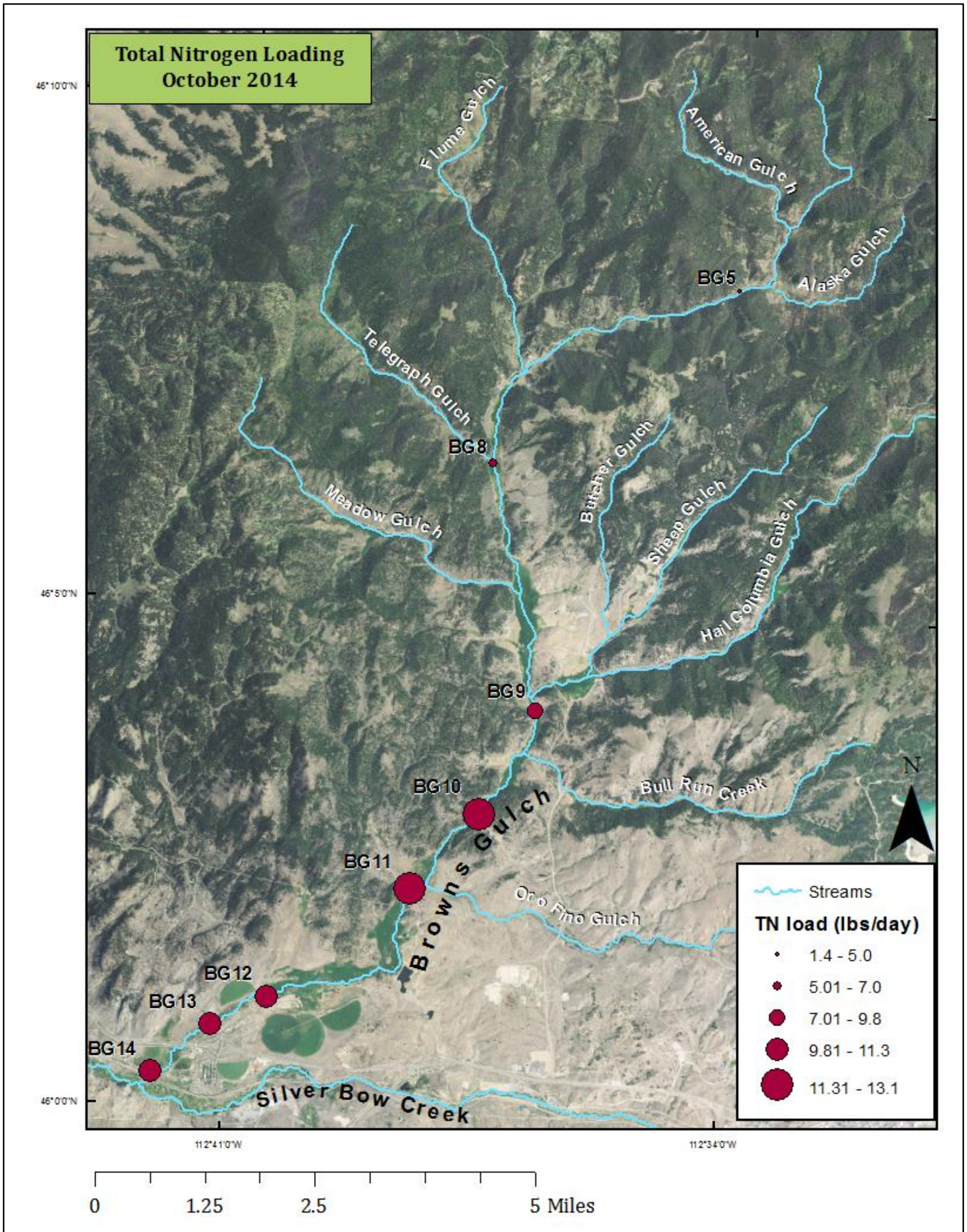


Figure G, 3. Total nitrogen loading represented with graduated symbols for October, 2014.

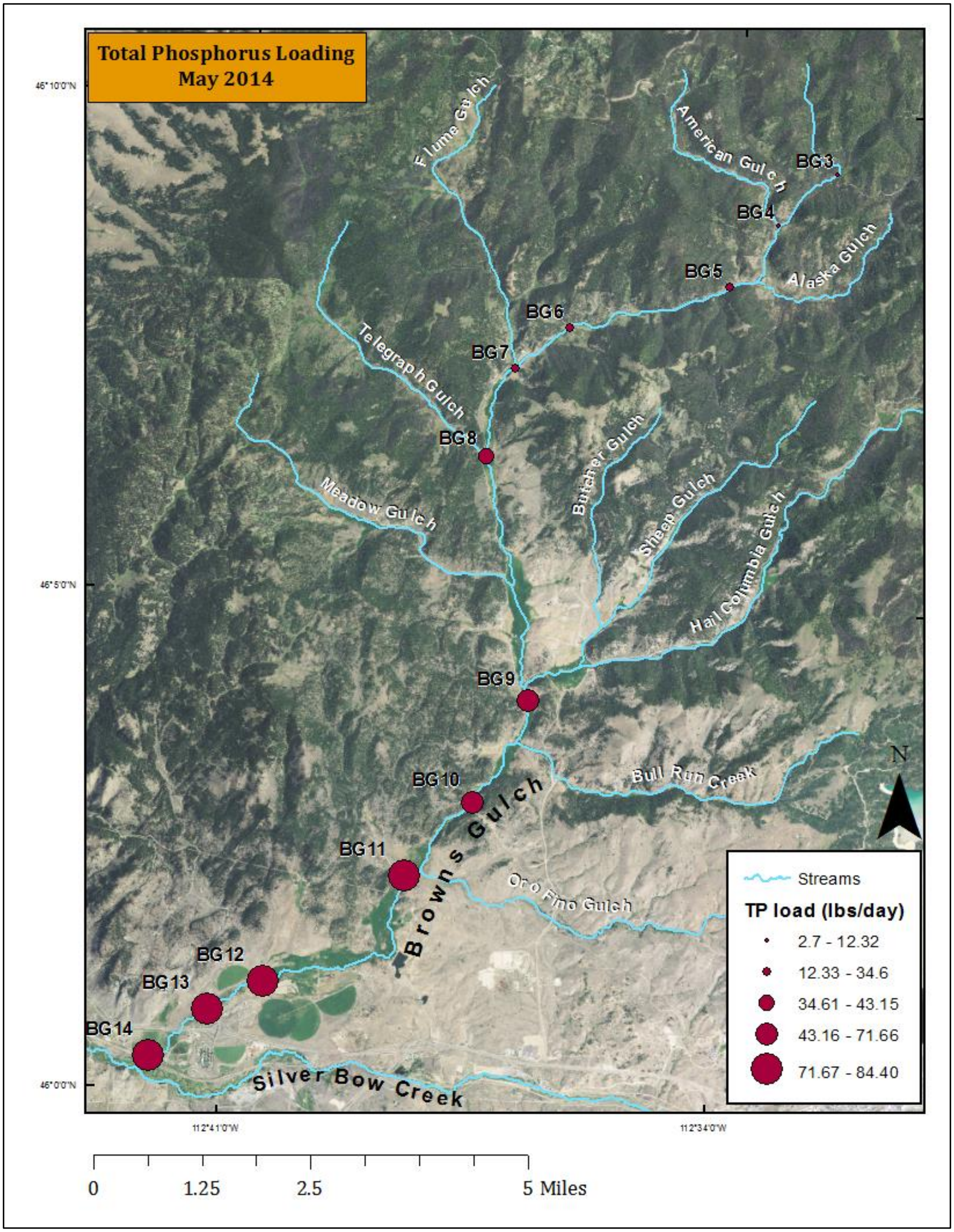


Figure G, 4. Total phosphorus loading represented with graduated symbols for May, 2014.

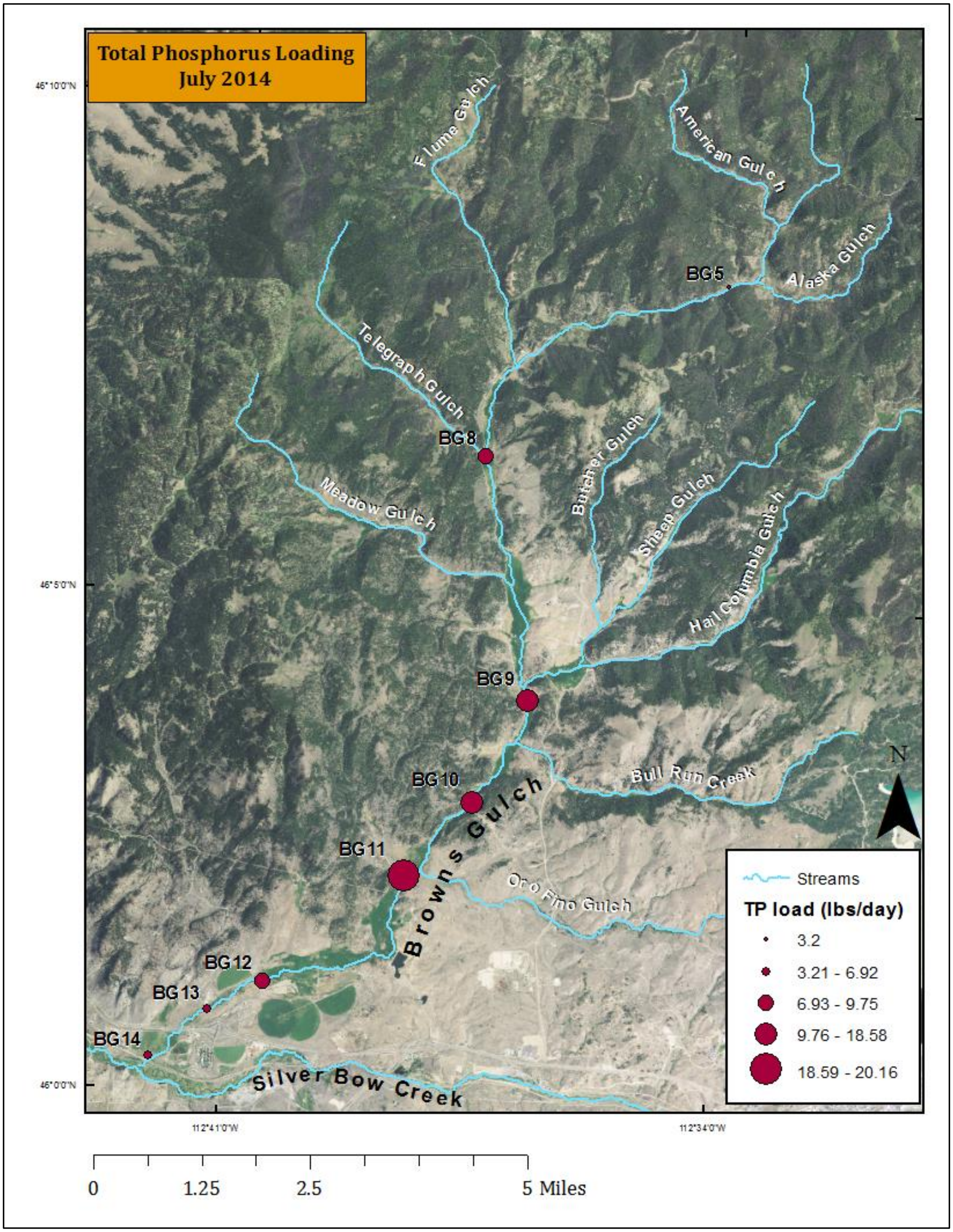


Figure G, 5. Total phosphorus loading represented with graduated symbols for July, 2014.

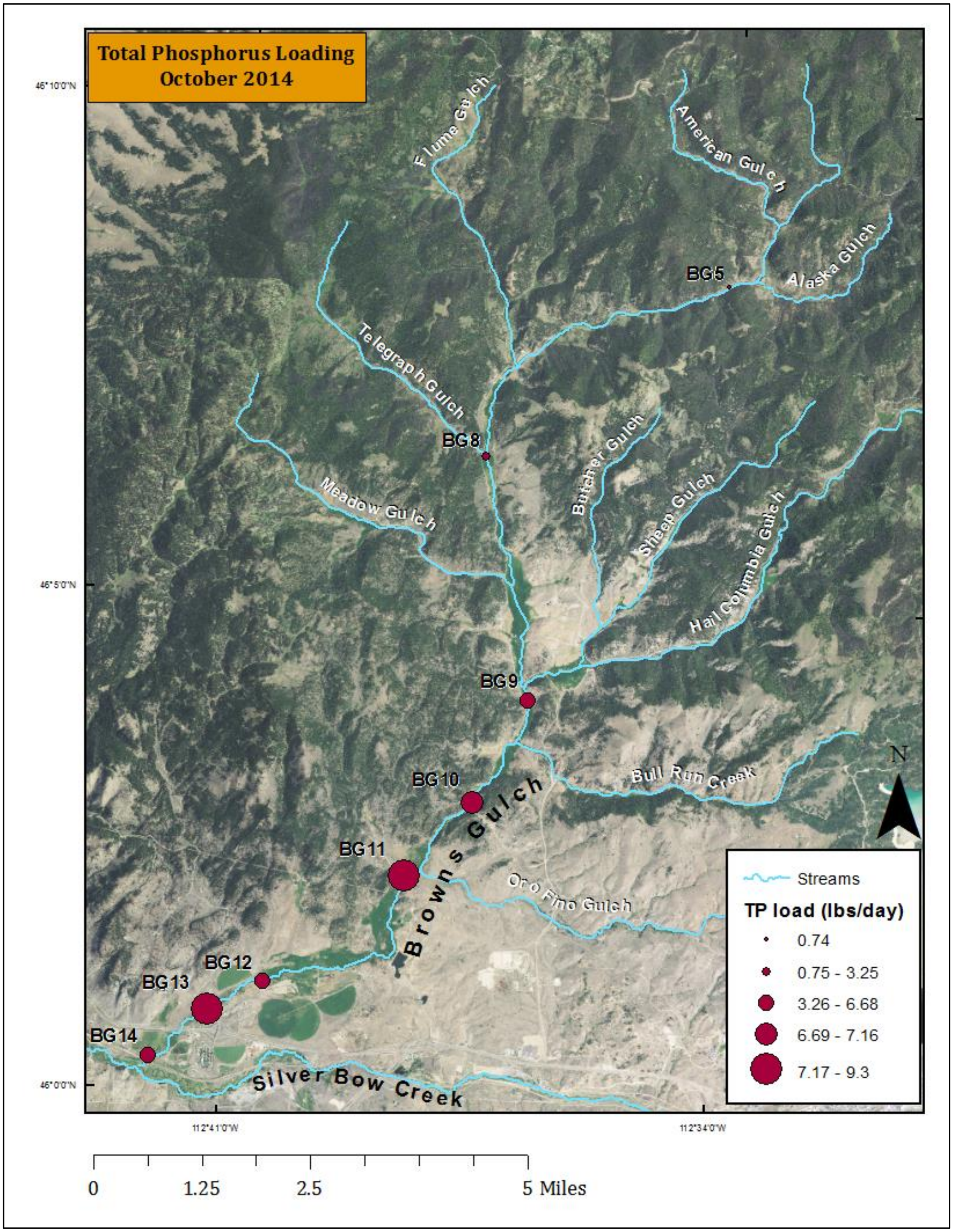


Figure G, 6. Total phosphorus loading represented with graduated symbols for October, 2014.

SIGNATURE PAGE

This is to certify that the thesis prepared by Sarah Hamblock entitled "Identification of Non-point Sources of Nutrient Loading and Recommended Best Management Practices for Browns Gulch, Silver Bow County, MT" has been examined and approved for acceptance by the Department of Environmental Engineering, Montana Tech of The University of Montana, on this 30th day of April, 2015.

Raja Nagisetty, PhD, Professor
Montana Tech of The University of Montana
Department of Environmental Engineering
Chair, Examination Committee

Steve Anderson, PhD
Water and Environmental Technologies, LLC.
Member, Examination Committee

Bill Drury, PhD, Professor
Montana Tech of The University of Montana
Department of Environmental Engineering
Member, Examination Committee

Jeanne Larson, MS, Professor
Montana Tech of The University of Montana
Department of Environmental Engineering
Member, Examination Committee

Gary Wyss, MS
Montana Tech of The University of Montana
Center for Advanced Mineral and Metallurgical Processing
Member, Examination Committee